Rothamsted Experimental Station
Harpenden

LAWES AGRICULTURAL TRUST

REPORT

for

1950

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THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914-1915.

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The purpose of the Society is to collect funds for continuing and extending the work of the Rothamsted Station.

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Special part-time worker	F. Tattersfield, D.Sc., F.R.I.C., O.B.E.

Assistant Staff	A. J. Arnold, Patricia Ball, R. Hinton, Jean Holland, Barbara Hopkins, Vanda Howard, Jill R. Kerridge, Jean Taylor, K. J. Townsend

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Assistants to Farm Manager	G. F. Cole, C. R. L. Scowen
Secretary	Pauline Cope
Typist	Ann S. Fakes
Foreman	H. P. Currant
Farm Workers	T. E. Ablewhite, A. Atkinson, J. Bird, P. Bird, F. Burton, W. Cain, H. S. Chapman, P. Currant, B. Day, K. V. Ewing, A. Mills, Deirdie A. Rawes, K. Sears, E. Stevens, F. Stokes, J. Underhill, H. A. Walford, F. West, L. Wright

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Librarian's Assistants ..	K. Toni Sumner, Sheila Webb

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Director's Personal Assistant	Mrs. H. Ashby Smith
Senior Assistants	Mrs. S. Coleman Mildred E. Ashford
Clerks	Joan Gardner, Ray Pepper, Ann Potter, Stella Smith, Beryl Thorne
Part-time Assistant ..	Barbara J. Bushell

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Part-time Draughtswoman	Barbara J. Bushell

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Assistants	MRS. K. M. KIRKWOOD, MRS. C. MELDRUM, MRS. A. SPEYER

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Caretakers, Cleaners, Gardeners, etc... ..	L. ALLEN, B. G. BURGESS, W. S. FISHER, J. H. HALL, MRS. HAMILTON, F. HAMILTON, F. K. HAWKINS, G. E. HOOPER, T. JACKSON, E. NEEDHAM, R. C. PARROTT, MRS. PARROTT, W. J. SMITH, MRS. SMITH, A. P. SNOWLING, F. J. STOCK, H. A. WESTON

Members of the Scientific Staff who left between January and December, 1950

Botany Department ..	WINIFRED E. BRENCHLEY, O.B.E., D.Sc., F.L.S. (retired)
Chemistry Department ..	ELIZABETH RICKSON, B.Sc. EDNA ROCKLIFFE
Insecticides and Fungicides Department ..	EILEEN M. GILLHAM, B.Sc.
Librarian	ISOBEL M. WAY, M.A.
Soil Microbiology Department	P. C. T. JONES, B.Sc., A.R.C.S.
Soil Survey of England and Wales	W. M. BAKER, B.A.
(Working at Royal Institution)	P. G. OWSTON

The following spent varying periods as temporary workers at Rothamsted during 1950

Australia : R. S. Beckwith (Chemistry), R. J. Best (Plant Pathology), S. M. Bromfield (Soil Microbiology), T. J. Marshall (Physics), K. Norrish (Pedology), J. P. Quirk (Physics), E. J. Williams (Statistics), Gwyneth R. Wykes (Bee Research)

Belgium : R. H. Kips (Nematology), J. Voets (Soil Microbiology)

British West Indies : E. M. Chenery (Pedology) (now East Africa)

Canada : R. H. E. Bradley (Plant Pathology), E. Helen Salkeld (Insecticides and Fungicides), R. S. Willison (Plant Pathology)

Denmark : H. C. Aslyng, M.Sc., Ph.D.

East Africa : H. C. Pereira (Physics)

Egypt : M. H. Hassanein (Bee Research)

Eire : J. D. Golden (Physics)
France : M. Ritter (Nematology)
Holland : J. W. Seinhorst (Nematology)
India : T. D. Mukerjea (Insecticides and Fungicides), T. S. Sadivasan (Plant Pathology)
New Zealand : I. D. Blair (Soil Microbiology), W. B. Taylor (Statistics)
South Africa : J. R. A. Coutts (Physics), A. C. Venn (Chemistry)
Spain : J. L. Garcia Vincente (Pedology), F. Martinez (Plant Pathology), M. Rubio (Plant Pathology), E. V. Vieitez (Field Experiments)
Sweden : H. G. Leyon (Plant Pathology), K. Nilsson (Soil Microbiology), B. Noren (Soil Microbiology), S. F. N. Oden (Physics)
Switzerland : L. Cavazza (Physics)
Tasmania : J. H. Wilson (Botany)
U.S.A. : M. B. Russell (Physics)
West Africa : Gold Coast—J. Quartey (Statistics), P. H. Nye (Pedology)
Nigeria—R. Miller (Statistics), P. Mulholland (Statistics)
British Isles : J. Chambers (Nematology), E. M. Clegg (Physics), Muriel E. Davies (Statistics), F. G. Gamble (Plant Pathology), Angela Gore-Brown (Soil Microbiology), M. V. Jackson (Chemistry), N. B. Joy (Plant Pathology), B. R. Laurence (Entomology), B. McKinley (Insecticides and Fungicides), J. C. Murdoch (Statistics), J. S. Murray (Plant Pathology), J. A. Nelder (Statistics), G. Newton (Statistics), S. C. Pearce (Statistics), J. A. Pope (Statistics), D. H. Rees (Statistics), Pamela Saich Plant Pathology), J. E. Satchell (Entomology), K. Slater (Statistics), G. W. Smith (Physics), P. T. Walker (Insecticides and Fungicides), R. Wickens (Statistics), Hilary Wilton (Statistics), J. K. R. Wood (Statistics).

Soil Survey of England and Wales

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Deputy Head	D. A. Osmond, M.Sc., Ph.D., A.R.I.C.
Soil Surveyors	B. W. Avery, B.Sc.
	C. L. Bascomb, B.Sc.
	A. Crompton, B.Sc.
	E. Crompton, M.Sc.
	I. L. Freeman, B.Sc.
	J. F. Harrop, B.Sc.
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	D. W. King, B.Sc.
	D. Mackney, B.Sc.
	W. A. Mitchell, B.Sc.
	J. A. Pollok, B.Agr.Sc.(N.Z.), M.F.(Minnesota)
	R. S. Seale, M.A.
	C. J. Tapp, B.Sc.
Chemists	H. H. Le Riche, B.Sc.
	C. L. Bascomb, B.Sc.
Assistant Staff	Doreen Bagnell, Marion Cater, D. V. Jones, G. A. Rudd

Woburn Experimental Station

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Assistant Director ..	H. H. Mann, D.Sc., F.R.I.C. (Kaisar-i-Hind Gold Medal)
Chemist	T. W. Barnes, M.Sc., F.R.I.C.
Assistant for Work ..	G. Pearce

Farm Staff

Farm Manager	J. R. Moffatt, B.Sc., N.D.A., A.I.B.A.E.
Assistant	G. F. Cole
Foreman	A. W. Neill
Farm Workers	Clara E. Horn, D. Mead, K. Wilson, W. Wilson
Part-time Workers ..	W. A. McCullum, A. Sibley, G. Tyler

Imperial College of Science and Technology

(Research Institute of Plant Physiology)

Director	F. G. Gregory, D.Sc., F.R.S.
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	W. W. Schwabe, B.Sc., Ph.D., A.R.C.S.
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	Dorothy Ridgway, B.Sc., A.R.C.S.
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The Commonwealth Bureau of Soil Science

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The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them, and by rendering any technical assistance possible when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Commonwealth and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assistants in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly 60 years. Lawes died in 1900 and Gilbert in 1901 ; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943 when the present Director Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory ; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income of which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent. of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919 ; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund ; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room, and Conference Room.

Since 1945 Rivers Lodge, a house belonging to the Station, on the south side of the laboratories, has been used to provide accommodation for the Statistical Department.

In 1946, Rothamsted Lodge, the dower house of the Estate, was purchased and occupied by the Entomology and Bee Research and Advisory Departments.

In 1947, the plant nematology work under Dr. T. Goodey, of the Institute of Parasitology was transferred to Rothamsted and a new laboratory was erected to house this department.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

A large new South Wing was completed in 1940, and the old chemical laboratories were reconstructed. These extensions and reconstructions have provided excellent accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments ; in addition a fine range of pot-culture houses was built. A new laboratory has also been built and equipped for workers from the Imperial College of Science and Technology.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields

being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930-32 and equipped for electric light and power. Further additions were made in 1939-40, and the electricity supply has now been extended to these newer buildings.

A further range of six farm cottages was erected in Ninnings Field in 1948, and a concrete road constructed from the back of the laboratories to the farm.

The non-experimental part of the farm was reorganized in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced, and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but the Station gains considerably by this closer association with the Universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934, the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted Estate were completed. The Rothamsted Trustees now own the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house, and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers, and from oversea sources.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually spreading out to the Commonwealth and other countries. The Station regularly participates in work for the solution of agricultural problems of great importance to the Commonwealth.

The Station offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soil Science, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

The Library

The Library may be said to have come into being in 1913, when the Sir Henry Gilbert Collection, presented by Lady Gilbert, was added to the small body of reference works used in the Laboratory at that time—most of them the gift of Sir John Lawes himself.

Its expansion, aided by gifts and grants from a number of individuals and Societies, was rapid, until it now contains :

	(Approximately)
Periodicals .. .. (Current, 1,100)	2,500
Books, 1841-	10,000
Books, 1471-1840 .. .. .. (including 14 incunabula)	3,500
Bound volumes of pamphlets ..	350
MSS.	55
Maps	300
Prints	100

—in all about 16,000 items, comprising some 38,000 volumes.

The yearly accessions of books and periodicals, bought and exchanged, amount to approximately 1,100 volumes.

The chief periodicals on agriculture and related subjects published throughout the world are received, either by subscription or in exchange, and constitute the most used section of the Library.

The stock of books also covers a wide range of subjects—not only agriculture but also, e.g., chemistry, physics, biology, botany, geology, zoology, meteorology and statistics. The books are arranged according to the Universal Decimal Classification system. The collection of early printed books (1471-1840), which is kept separate from the rest, includes 14 incunabula, amongst which is a copy of the first dated edition of Pier de' Crescenzi's *Ruralium commodorum libri duodecim*—the earliest printed book on agriculture—produced at Augsburg by Johann Schüssler in 1471 (Hain 5828). The collection of MSS. includes a copy of the *Treatise of Husbandry* by Walter of Henley (fl. 1250), written in England on vellum about the middle of the 14th century.

The prints, which are mainly of the 18th and early 19th centuries, include portraits of eminent agriculturists, bucolic scenes, and representations of livestock.

A most valuable addition to the collection was made in 1948 when Lord Northbrook presented his Father's collection of prints to the Station.

The Library is designed to meet the requirements of the staff of Rothamsted ; but its use is extended to any research worker who can show his need of it.

The General Catalogue of the Library is kept on cards. There is also a published catalogue of the collection of early printed books (Rothamsted, 1926 ; second edition, 1940) of which a third edition, completely revised and expanded, is being prepared. Work is about to begin on a printed catalogue of periodicals.

INTRODUCTION

By the Director

Staff

Dr. E. M. Crowther and Mr. F. C. Bawden, F.R.S., have been appointed Deputy Directors of the Station responsible for the Soil and Plant Pathology Divisions respectively. There have been no major changes amongst the senior scientific staff, but a few of the junior members have left to take up posts elsewhere and several new appointments have been made. Mrs. M. J. Way resigned her position as Librarian and was succeeded by Mr. D. H. Boalch, M.A.(Cantab.), F.L.A. Dr. T. Goodey, F.R.S., was awarded the O.B.E. in the 1950 New Year's Honours.

The Director was elected a Foreign Member of the Royal Academy of Agriculture of Sweden.

Dr. A. H. McIntosh, of the Insecticides and Fungicides Department, has spent the year at the Connecticut Agricultural Experiment Station on an exchange basis with Mr. Neely Turner, the senior entomologist of that Station. Mr. M. J. Way has been seconded to Zanzibar for entomological work on Sudden Death of Cloves, and the secondment of Dr. F. M. Roberts on the same scheme has been extended. Mr. W. W. Emerson spent three months at the University of Madrid, assisting in the preparation of the English translation of Professor W. Kubiena's new book on the Systematics of European Soils and studying his micro-pedological technique.

Rothamsted was represented at the following conferences: the 4th International Congress of Soil Science, Amsterdam, the 7th International Botanical Congress, Stockholm, and the 5th International Congress of Microbiology, Rio de Janeiro. Dr. E. M. Crowther was Chairman of the Soil Fertility Section of the Soil Science Congress and Mr. F. C. Bawden was Vice-President of the Phytopathology Section of the Botanical Congress. He was also President (*in absentia*) of Section VII (Plant Pathogenic Microorganisms) of the Congress of Microbiology. The Brazilian Government generously provided the travelling expenses for a delegate from Rothamsted and Dr. P. H. Gregory was chosen to represent the Station.

Mr. F. C. Bawden gave a course of lectures on Plant Viruses and Virus Diseases for six weeks at Yale University; he also attended a conference on viruses at the California Institute of Technology, Pasadena, and visited other Universities and Research Stations in the United States and Canada. Dr. F. Yates attended the Fourth Session of the United Nations Sub-Commission on Statistical Sampling at Lake Success. Whilst in the United States he represented Rothamsted at the 75th Anniversary of the Connecticut Agricultural Experiment Station, the oldest agricultural experiment station in the United States, and one with which Rothamsted has for many years had close links.

The Director spent two months in Canada as leader of a United Kingdom Agricultural Mission. The Mission were guests of the Canadian Government and visited all the leading agricultural teaching and research centres throughout Canada.

Visitors

Several thousand visitors from 30 countries came to the Station in 1950. These included many foreign or Dominion scientists who spent some time at Rothamsted in the course of their journey to or from the International Congresses held at Amsterdam and Stockholm. The visiting parties included the Parliamentary and Scientific Committee, and a Parliamentary delegation from Iceland. There were parties of farmers from Norway and the United States, and agricultural students from Norway, Denmark, Belgium, Eire and the United States. In July a visit was paid to Rothamsted by delegates of the Commonwealth Agricultural Bureaux Review Conference.

Buildings

A new field laboratory was completed for the Bee Department, which relieved the congestion in that department. During the year a start was made with the conversion of the Manor House as a Hall of Residence, and the old Sample House near the main laboratory buildings is being fitted up as a library annexe and institutional store. Plans have been prepared and estimates obtained for a new building which will house part of the plant pathology group of departments. It is also hoped to provide a new building to house the Statistics department which has expanded considerably with the creation of the Statistical Research Service.

The Work of the Station

A considerable amount of work has been done in the Pedology department during the year on the clay mineralogy of soils from a wide range of conditions. The interdependence of soil clays and soil parent material has been clearly brought out in the study of the Malvern Hill soils and also in a series of soils from Syria. An examination of the clays from soils of the groundnut areas in Tanganyika gave no clue as to the curious physical behaviour of the soils. In the study of waterlogged soils it has been shown that the reduction of iron oxides can be effected by sterile fermented grass extracts so that the process is not entirely microbiological.

Increases in the prices of fertilizers make their efficient and economical use more important than ever, and in particular restrictions in the supply of sulphur render it necessary to economize in the use of superphosphate, and to test other phosphatic fertilizers. For many years much of the work of the Chemistry department has been directed to these ends. In a series of experiments mostly on very acid soils, silico-phosphate proved to be just as effective as superphosphate for swedes and reseeded grass, but not so good for potatoes and cereals. In the fertilizer placement experiments it has been confirmed that placement is advantageous in the case of quickly growing crops with shallow roots, e.g., peas, beans and spinach, but not for deeply rooting crops with long growing seasons, e.g., sugar beet and carrots. The search for a slow-acting nitrogenous fertilizer has been continued and so far the most promising results have been obtained with formalized casein, a plastic waste product. Progress has been made with nutrition problems in forest nurseries, and the value of fertilizers, properly

used, has been established. Steam and formalin treatments gave striking results in certain cases and these are being investigated. Part of the effect is probably due to control of soil fungi and other organisms but there are indications that most of the benefit may arise from the maintenance of high ammonium concentration in the soil. The study of soil organic matter has been continued and in a range of contrasted soils it has been found that the protein materials were very similar in composition. The long-term residual benefit of farmyard manure on Hoosfield appears to be largely due to its inorganic constituents, since superphosphate had similar effects. The radio-active tracer technique has been used to study the behaviour of added phosphate in soil and it has been shown that in a Broadbalk plot which has received superphosphate annually for over a century about one-fifth of the total phosphorus was in a readily exchangeable form whilst it was negligible in a plot without superphosphate. Work on manganese deficiency has been continued. The state of oxidation of manganese in the plant depends on the production of hydrogen peroxide and in the Biochemistry department two enzymes, an amine oxidase and an aldehyde oxidase have been studied in this connection.

There can now be little doubt that the weather is the dominant factor determining the water requirements of all kinds of vegetation. Using the method worked out in the Physics department, the Agricultural Meteorological Branch of the Meteorological Office issued fortnightly estimates of the inches of water evaporated from green vegetation at stations throughout England and Wales during the summer of 1950. These estimates serve as a guide to irrigation, since if the inches of evaporation exceed the inches of rain the difference is the inches of irrigation that must be applied to replace the moisture drawn from the soil. As a further check, calculations have been made of the mean annual evaporation at one hundred stations in the British Isles, and the results have been compared with the excess of rainfall over river discharge in forty catchment areas. The agreement is very satisfactory. The results may also be used to estimate the surplus of rainfall over evaporation available for meeting the water needs of the country. A theoretical study of the processes of diffusion of water vapour through the stomata of the leaves of plants has further substantiated the validity of the principles underlying the calculations. The physico-chemical approach to the study of soil fertility is giving interesting results. It has been found that on shaking up a soil sample with water containing about as much calcium salt as is normally present in soil water, a very small but quite definite concentration of phosphate is established in a few minutes. This test applied to soil known to be deficient in phosphate gives concentrations so low that they can only be measured with the aid of special equipment, and for this reason solvents giving higher concentrations for analysis have been preferred in advisory work. The use of acid solvents appeared to be justified by the older view that acids are secreted from plant roots ; but as there is no real foundation for this view the results obtained by the use of acid solvents may be misleading. Other substances beside phosphate—some desirable and others undesirable —are also present at very low concentrations in the soil solution, and techniques for studying them are being developed. If it can

be shown that the soil solution remains in physico-chemical equilibrium with the solid substances this will facilitate the interpretation of the results of laboratory tests.

One of the aims of soil microbiology is to learn how to change the microscopic population of soil in a useful direction. In the Soil Microbiology department in co-operation with the Chemistry department, the effects of treating soil, in the field, with steam and formalin have been studied. Striking changes in composition of the soil micro-population resulted from these treatments and have lasted in some cases for over a year from the time of soil treatment. An abundant group of soil microbes, the actinomycetes, include many species that secrete antibiotic substances of which streptomycin is an example. This suggests that such organisms might be used to control those that produce root diseases. For this to be possible it is clearly necessary that the actinomycetes to be used should grow actively in the soil and should produce an antibiotic that is active and lasting in it. Actinomycetes that produce secretions active in laboratory culture against a root disease fungus have been found and the conditions under which they will grow and produce active antibiotic secretions have been investigated. Since it is important to know how far the actinomycetes exist in the soil in an active state or as spores, a method for finding this out has been developed and is under test. Many plants have specific fungi associated with their roots (mycorrhiza) and in some cases there is evidence that the fungus benefits the plant. Such associations are found in crop plants such as clover and wheat but there has been no evidence as to whether the crop benefits from them. Experiments have been made in which clover was grown in sterilized sand supplied with a series of diluted suspensions of fresh soil. In some pots mycorrhizal associations were found to have developed and in others there were none, but no corresponding difference in growth of the clover was observed. The factors in the clover that influence the appearance of nodules on its roots have been further studied and there is evidence that nodule production and numbers are controlled by some substance secreted from the roots.

Work done in the Botany department during the year followed the same lines as described in 1949. The micro-nutrient investigations were on the interaction of molybdenum and manganese and no evidence has yet been found to support the claim made elsewhere that increased molybdenum supply mitigates the toxic effect of excess manganese. Further progress has been made in the studies of nutrient uptake by excised roots and by leaves. In the case of excised roots it has been shown that the rates of uptake of nitrate, phosphate and potassium all depend on the total soluble carbohydrate content of the roots but not specifically on sucrose or reducing-sugar content. The rate of uptake of each of these nutrients decreases with increase in the concentration of the same nutrient in the root. The uptake of appreciable amounts of nitrogen, phosphorus and potassium from nutrient solutions sprayed on leaves has been confirmed for cabbage, sugar beet, french beans and barley. Similar amounts of nitrogen were taken up from solutions containing ammonium or nitrate ions in equal concentrations. The growth and yield of sugar beet plants was increased by spraying the leaves with nutrient solutions. In a study of the manner in which germina-

tion of seeds depends on water supply, it has been found that in the first phase of water uptake the seed behaves as a physical system, the course of water uptake being similar in living and dead seeds. In living seeds there is a second phase associated with growth of the embryo. Fairly simple mathematical formulae have been found to express the variation of water content with time. In the investigations on wild oats it has been shown in laboratory tests that farmyard manure hastens the germination of dormant seeds, and this is being tested on a field scale. Further work has been done to find out how infection with leaf-roll virus affects the growth of the potato plant. Reduction in yield would appear to be due mainly to decreased assimilation by the leaves that are rolled, but leaf area is also smaller in infected plants.

In the Plant Pathology department studies on the nature of viruses were continued. Further work has been done on the proteins specific to virus-infected plants, and it has been shown that only part of them can bring about infection. Investigations have been made on a number of crops including potatoes, sugar beet, lettuce, cauliflower, cabbage, groundnuts and cacao. Techniques were devised for using radio-active phosphorus to study the feeding and movements of the aphids concerned in virus transmission. As a result of six years' experiments it was concluded that roguing potato crops in south-east England did not reduce virus diseases sufficiently for the practice to be worth while, but preliminary experiments in co-operation with the Insecticides department indicate, that spraying with "systemic" insecticides reduces the spread of leaf-roll. There has been a great increase in sugar beet yellows since the production of sugar beet seed was started in this country during the war. Control measures on steckling beds have been developed and a health certification scheme introduced in 1950 when more than half the stecklings for the seed crop of the country were raised in isolation, under cover crops or sprayed. The mycological work was mainly on cereal diseases and a new disease of oats was discovered, caused by the same fungus (*Corticium solani*) as that causing sharp eyespot of wheat. Work on clubroot was continued and experiments on potato blight and cereal mildews started. A study has been made of the new disease attacking sycamore trees in the East of London and the fungus which appears to be responsible has now been identified as *Coniosporium corticale*, hitherto known only on maple in Canada and the United States.

In the Biochemistry department work has been continued on normal and virus-infected leaves. Normal tobacco leaves contain an unstable nucleoprotein which is sedimentable on the ultracentrifuge ; the amount separated can be as much as 10 per cent of the protein of the leaf, and probably more remains attached to the fibre. This is a regular contaminant of all plant virus preparations made by methods designed to keep the virus in its original state. Using the experience gained with this material, progress has been made in understanding the changes that a tobacco necrosis virus undergoes in the process of isolation, and it has been suggested that much of the infectivity of a preparation is acquired after the virus has been liberated from the cell, as preparations made from sap that has stood for some time are more infective than those newly

extracted. This possibility becomes important when one is thinking about the mechanism of virus infection and the possibilities of control. Work on the large-scale separation of leaf protein continues. A mill and press have been designed which deal satisfactorily with grass and other leafy material on a pilot plant scale. Heat coagulation and separation of the protein present no particular problem.

In the Nematology department work has continued on the host ranges of several species and biological races of plant eelworms, especially the oat and narcissus races of the stem and bulb eelworm (*Ditylenchus dipsaci*), the potato tuber eelworm (*D. destructor*), and the strawberry eelworm (*Aphelenchoides fragariae*). Results of cross-infestation tests with the chrysanthemum and blackcurrant eelworms support the probable identity of these two species, *Aphelenchoides ritzema-bosi* and *Aph. ribes*. Pot tests show that the population of potato root eelworms (*Heterodera rostochiensis*) can increase 35-fold in one season, invasion of potato roots being heaviest in the first few days after planting. Sub-lethal doses of soil fumigants can also lead to population increases. A study of the conditions under which eelworm larvae are stimulated to hatch, by substances diffusing from the roots of growing potatoes, has led to an abbreviated hatching test and also to a method for the bio-assay of such diffusates. In soil, the latter are very localized in action and are rapidly broken down. The beet eelworm on Barnfield has not appreciably increased in numbers; it is most numerous on the plots giving the highest yields.

The work of the Entomology department consists of fundamental studies into the causes of insect outbreaks, and investigations of special problems relating to particular pests. Continuation of the work previously reported on measurement of insect populations has shown that most of the fluctuations in numbers can be accounted for by the rainfall and temperature of the previous three months. In the study of insect migration new evidence of autumn movements to the south has been obtained; there was very little influx of pests into Britain in 1950. New suction traps which separate out the catch for each hour of the day and night are throwing new light on insect activity and the drift of insects in the upper air from one district to another. One result is the demonstration of two peaks in activity, morning and afternoon, in many species of aphids. The forest soil studies have shown unexpectedly great numbers of "mites" (*Acari*), which outnumber the insects in many places. The earthworm investigations include tests of a new electrical technique for bringing the worms to the surface, so that the species and numbers can be determined. In co-operation with the Insecticides and Fungicides department work on the effect of various insecticides on the wireworm populations has been continued and a study is also being made of the increase of wireworm numbers in leys. Work on the swede midge has shown that it has a much greater range of food plants than was known and can attack many different parts of the plant. A further volume of Dr. Barnes' *Gall midges of economic importance* has been published.

In the Bee department work has been continued on the behaviour of the honeybee in the field. A study has been made of the effective flight range and the influence of distance on honey yield. The results bring out the disadvantage of placing a large number of

colonies of bees in a single apiary. It would appear that foraging bees are unable to communicate to other bees the colour or shape of plants on which they are feeding. A survey has been made of the sugars in nectar of various plants, and it has been found that bees prefer nectars containing equal proportions of glucose, fructose and sucrose. The investigations on bee breeding have been extended and a new type of syringe tip for instrumental insemination has been devised which promises to simplify the operation and to reduce the risk of damage to queens. Work is in progress on the feeding of colonies in spring and autumn and it has been found that in autumn it is more economical to feed the sugar as a concentrated syrup. Work has also been done on the feeding of pollen supplement in spring, and it has been found that the addition of a small trace of yeast to soya bean flour makes this a more effective food than the well-known soya bean flour and pollen mixtures.

The Insecticides and Fungicides department has continued work on various aspects of insecticidal action and the factors affecting the resistance of insects to insecticides. Differences in particle size of D.D.T. and rotenone had previously been shown to give differences in toxicity and injection experiments have now provided evidence that this is linked with the capacity to penetrate the insect cuticle. A study has been made of the mechanism of the toxic action of the new group of organophosphorus insecticides. In addition to their anti-choline esterase activity already recognized other esterases may be important. One aim in this work is to obtain compounds more toxic to insects and less poisonous to human beings. The synthesis of compounds allied to pyrethrins has been further studied, and insecticidal tests have given some information on the structural characteristics of molecules of this type which are associated with toxicity. In connection with the biological testing of insecticides, methods have been improved both for injection into insects and for contact applications. Preliminary work on insecticidal deposits on plants has shown that temperatures of leaves exposed to the sun may be considerably above air temperature and that D.D.T. deposits can volatilize comparatively quickly under these conditions. Field experiments on the control of wireworms have been previously reported and increased crop yields have been observed three years after soil treatments with B.H.C., D.D.T., ethylene dibromide and D.D. In the experiments on the control of black aphis on field beans parathion, H.E.T.P. and nicotine gave good results. D.D.T. not only gave a low kill but the treated plots ultimately had a much larger infestation than the control, probably due to the destruction of beneficial insects. Preliminary tests indicated that allethrin, the pyrethrins and dieldrin were effective insecticides against this pest.

In the Statistics department, an increasing amount of work has been undertaken for the National Agricultural Advisory Service, in addition to the usual assistance given to workers at Rothamsted and other stations at home and abroad. A start has been made on the investigation of experiments on animals. The Survey of Marginal Land was completed early in the year, and the third and last year's field work on the Survey of Maincrop Potatoes has also been carried out. Analysis of the 1949 results of this latter survey again gave an overall yield estimate in excess of the official estimate. The Survey

of Fertilizer Practice covered nine districts during the year, with a view to investigating changes following the reduction of subsidies, and a survey of restored open-cast coal sites is in its preliminary stages. The Hollerith punched-card computing equipment has been modified to permit greater flexibility of operation, and has been in continuous use in a number of investigations.

Investigations on the growing of hybrid maize, soya beans and other exotic crops have been continued at Woburn and the work on clover sickness has followed the same lines as last year. The number of plots laid down in 1950 on the Rothamsted and Woburn farms was 2,056, the largest number ever attempted. Over two-thirds of these were accounted for by the Classical experiments and the long-period rotation experiments on present-day husbandry problems. The most recent is the experiment testing different ley and arable rotations which completed its second preliminary year in 1950. This preparatory period is being used to develop grazing and sampling techniques. The experiment will attain full cycle with some 450 plots in the spring of 1951. Two long-period experiments have been terminated and fully reported: a test of the continued use of salt on sugar beet, and a potato experiment whose main purpose was the study of the spread of virus disease but which also tested the influence of time of planting on fertilizer action. New annual experiments were started to examine the effects of very late applications of nitrogenous fertilizer on the yield and quality of cereals. Promising increases in the production of crude protein, amounting to about 1 cwt. per acre, were recorded in 1950, which was probably a very favourable year for late top dressings. Wet weather in the autumn made harvesting operations very difficult. At Woburn the farm has been provided with modern and much needed additions to the farm buildings. Shortage of houses for farm workers, however, is giving rise to serious difficulties.

As in the past, the staffs of the various departments are greatly indebted to the farm manager and his assistants for their very willing and efficient co-operation.

DEPARTMENT OF PHYSICS

By R. K. Schofield

No change has occurred in the permanent staff during the year. Mr. I. F. Long was awarded a National Certificate in Applied Physics by the Institute of Physics. Dr. H. C. Aslyng was granted an extension of his scholarship by the British Council and was subsequently appointed Reader in Soil Science at the Royal Veterinary and Agricultural College at Copenhagen. He obtained the Ph.D. degree of London University.

In October Mr. J. P. Quirk, of the Soils Division of the Australian Commonwealth Scientific and Industrial Reaserach Organization, joined the depratment for a two-year period, and Mr. E. M. Clegg started a year of training for the Colonial Agricultural Research. Dr. L. Cavazza, of the University of Bari, Italy, spent two months of his summer vacation working in the department.

Dr. Schofield has continued to serve on the Joint Committee on Soils appointed jointly by the Department of Scientific and Industrial Research and the Ministry of Supply. The Technical Panel of the Land Drainage Legislation Sub-Committee of the Ministry of Agriculture's Central Advisory Water Committee, on which both Dr. Schofield and Dr. Penman served, presented its report in October.

Three members of the department attended the Fourth International Congress of Soil Science at Amsterdam, Dr. Schofield giving the special discourse to the section of Soil Physics. Useful contacts were made, and valuable personal reactions obtained to previous work of the department on soil moisture equilibria, evaporation studies and gaseous diffusion in soils. The department also supplied an exhibit as part of the section " Meteorology and Agriculture " of a Science Museum special exhibition to celebrate the centenary of the Royal Meteorological Society. Mr. W. W. Emerson was seconded for three months to the University of Madrid to assist in the preparation of the English translation of Professor Kubiena's new book on the Systematics of European Soils and to study his micro-pedological technique.

Soil Cultivation

Deep ploughing

The six-course deep cultivation experiment has now run seven years. Each of the six blocks of the experiment has carried a rotation of potatoes, spring oats, sugar beet, barley, ley and wheat, a different crop starting the rotation in each case. Half of the plots on each block have been deep-ploughed (12 in.–14 in.) for potatoes, sugar beet and wheat. At these times the remaining plots were shallow-ploughed (6 in.–8 in.), otherwise all plots in the same block have received the same cultivation treatments.

Depth of ploughing has had no consistent effect on the yields of potatoes grown without potash or with 1 cwt. K_2O per acre ploughed in ; but on all seven occasions (i.e. on every block in turn and on one block twice) the deep-ploughed plots which received

this amount of potash applied in the bouts yielded more than the corresponding shallow-ploughed plots. The difference was 3 tons per acre in 1948 and 1·8 tons per acre in 1945, but was less than 1 ton per acre in the other five years. Although a statistically significant benefit from deep ploughing under these conditions cannot yet be claimed, it is possible that it may emerge before the experiment is finished.

In 1947 the sugar beet crop yielded 47 cwt. of sugar per acre on the deep-ploughed plots and only 35 cwt. on the shallow-ploughed. In 1948 and 1950 the yields of sugar were some 5 cwt. lower on the deep-ploughed than on the shallow-ploughed plots, although the tops were slightly larger. In the remaining years the deep-ploughed plots into which 0·6 cwt. P_2O_5 per acre as superphosphate was incorporated by ploughing yielded consistently four to five cwt. more sugar per acre than the corresponding shallow-ploughed plots. Where superphosphate was applied in the seedbed it gave no consistent increase in yield, and there was no consistent difference between deep and shallow ploughing. It has nearly always proved more advantageous to plough-in superphosphate for sugar beet than to harrow the same amount into the seedbed.

There is, as yet, no sign that deep ploughing—which has now been carried out four times on some plots and three times on others—is producing any cumulative benefit. Interpretation of the data is complicated by seasonal effects. Thus in 1950 45·3 cwt. of hay was obtained from the ley plots deep-ploughed in 1948 for sugar beet, whereas 54·5 cwt. were obtained from the corresponding shallow-ploughed plots; but in other years the differences have not been significant. In the dry summer of 1947 the barley on the deep-ploughed plots yielded 32·4 cwt. per acre compared with 30.0 for the shallow-ploughed plots, whereas in other years the difference has been less than 1 cwt. per acre and insignificant. The yield of wheat was depressed 2·8 cwt. per acre in 1947 and 3·5 cwt. per acre in 1948 by deep ploughing, but in other years the effects have been smaller and insignifcant. No significant effects are to be seen in the yields of spring oats.

It has frequently been observed that fewer weeds germinate in the seedbeds on the deep-ploughed than on the shallow-ploughed plots. The contrast was particularly marked on the sugar beet plots of 1947, and severe weed competition before hoeing could be carried out may have been the main cause of the striking difference in yield already referred to. It is to be expected that this contrast will disappear in time, and in fact it was not observed in 1950.

Agricultural Meteorology

Irrigation

Two centres were used in 1950, one for sugar beet, the other a forest nursery. At Kesgrave, Ipswich, the sugar beet experiment followed the pattern described in previous reports, Dr. Penman, assisted by Mr. Long, being responsible for installation of meteorological equipment on the site and interpretation of the weekly records received. Although the summer was wetter than that of 1949 there was a positive gain from irrigation :

Yield of sugar (cwt.)

				Rain (from 1st May)
Total irrigation up to 1st July	0	2	$1\frac{1}{2}$	2	2·8
Total irrigation up to 1st Sept.	0	2	2	3	7·5
Total irrigation up to 25th Sept.	0	2	2	4	10·7
"Nitrochalk" (cwt./acre)					
0	52·4	63·9	58·8	60·9	
$2\frac{1}{2}$	51·9	67·2	59·9	65·9	
5	54·8	63·9	58·8	64·0	
$7\frac{1}{2}$	52·1	62·7	58·9	63·4	

The insensitivity of yield to nitrogen dressings was as in former years, but a new feature of the results was a significant difference in yield for two irrigation treatments giving the same total water. Future experiments at Woburn (see below) will be designed to check the implications of this result.

At Kennington Nursery, Oxford, the Research Branch of the Forestry Commission has started an experiment on controlled watering as a variable in seedbed experiments, and here, too, weekly weather records from the site have been the basis of controlled irrigation. Because of the shallow root layer of the seedlings, necessitating frequent small waterings, control from a distance has been difficult and the most that can be said of the experiment is that in spite of the wet summer, the watered beds have been better than those left to natural rain.

Drain gauges

The attempted repair of the 40-inch gauge appears to have been unsuccessful. Drainage totals for the year are: 20, 14·81 in; 40, 15·29 in.; 60, 14·32 in. Rainfall: 32·13 in.

Evaporation and transpiration

The agricultural application of the work is primarily in irrigation (as at Kesgrave). During the year the Ministry has made a grant for installation of equipment at Woburn, and from 1951 onwards this will be the main centre for field experiments on a variety of farm crops, and the experimental plots will provide useful opportunities for the study of physical and biological effects of irrigation. As forecast in the 1949 report, the Agricultural Meteorology branch of the Meteorological Office is now issuing fortnightly estimates (about one week in arrears) of potential transpiration for one or two places in each of the provinces of the National Agricultural Advisory Service, so that farmers—if they wish—can eliminate much of the guesswork from irrigation operations. Interest in this physical study of evaporation has been shown at many places abroad, to the great encouragement of the department; within one week there were requests for advice from the equator and from within the Arctic circle!

The work has been extended backward and forward. With Dr. Schofield, Dr. Penman has shown that an empirical factor connecting evaporation from vegetation with that from open water can be deduced theoretically from considerations of stomatal geometry and length of daylight, and extension of the ideas has shown that a

theoretical ratio of transpiration to assimilation can only be brought into line with observed values if concentration of carbon dioxide in the air cavities of leaves is always very close to the atmospheric value. This is a conclusion of some botanical significance and needs further testing.

In the first of two forward extensions, Dr. Penman has published an account of the water balance of the Stour catchment area showing that some of our water supply problems are amenable to a physical treatment that is more precise both in detail and in long-term behaviour than prevailing statistical correlations. An evaporation map of the British Isles has also been published, showing the estimated mean annual evaporation at a hundred places and checked very satisfactorily by figures of rainfall *minus* run-off for forty catchment areas. The evaporation ranges from 14 inches per annum in north Scotland to 21 inches per annum in south England, and it is clear from the known seasonal distribution that in most years much of England south-east of the line Severn-Humber has not sufficient summer rain to produce maximum crop yields.

Two general reviews of this work have appeared in 1950. The first is a survey of the physical aspects up to but not including the evaporation map, by Dr. Penman ; the second is a survey of the biological and agronomic aspects by Dr. Schofield, being an account of the special discourse he was invited to give at the International Soil Congress in Amsterdam.

Micrometeorology

Dr. Broadbent (Plant Pathology) has now published an account of his physical measurements among potato crops, based essentially on the thermistor bridge made in the Physics Department. His observations, necessarily discontinuous, have given quantitative measures of diurnal changes in environment that were predictable qualitatively. To fill in some of the gaps in the records, Mr. Long has successfully adapted the thermistors to be used with a continuous recording galvanometer, and an extended trial over a period of three months among brassica plants has been successful. From a first analysis of records Mr. Long has found interesting inversions of the vapour pressure gradient during some nights, but as it rained either before or during these periods the direct (qualitative) check of dew formation was not possible.

Mr. Long's first model of the thermistor bridge has been redesigned and has been on loan to the Grassland Research Station, Drayton, where it has provided some interesting and useful data on the micrometeorology of varied kinds of herbage.

The dew problem, of minor interest in British agriculture—except during hay-making—is supposed to be of major importance elsewhere, and the physical process is important even here in fog problems. Mr. Long is, therefore, attempting to construct—from thermistors—a small wet and dry bulb thermometer system that can be fitted in a probe for use in confined spaces. If it works we hope to get some measures of vapour pressure gradients in the soil to see if there is any appreciable upward movement of water vapour in the soil during the night.

Heat balance of the soil

Whatever the results of this experiment, the experience gained will be useful for a desirable extension of Dr. Hutchinson's work on heat flow in the soil. As noted in 1949, a set of thermometers has been installed down to 6 feet and connected to a 12-point recording galvanometer. Because the thermometers and recorder are necessarily some distance apart it is not possible to keep all the system at the same temperature, and to obtain reliable records it has been necessary to use good quality auxiliary components and to adjust them carefully. In spite of delayed delivery of components the job has been completed, and reliable records are now being obtained. In the meantime Dr. Hutchinson has worked out a neat method of analysis that will be of great value later. The next stage is to obtain corresponding records for heat flow in the air, for vapour transport in the air, and for radiant energy exchanges. For the first two the continuous recorder described above will be useful, and for the last, Dr. Hutchinson, assisted by Mr. Long, has started the construction of a portable radiation meter.

In all of this work close contact is being maintained with the radiation laboratory of the Meteorological Office at Kew Observatory.

Laboratory Work

Soil structure

The general problem of evaluating quantitatively the difference between soils with good and bad structure has been investigated by Mr. W. W. Emerson with particular reference to two clay soils from the Grassland Research Station at Drayton. These have approximately the same mechanical analysis, but one had been under arable cultivation for four years and had so bad a structure that it was considered necessary to put it down to ley, while the other had just been ploughed-out after four years in ley. These will be referred to as "arable" and "ley" soils.

There are two interpretations of bad structure, possibly interrelated. Firstly, a low water stability producing a break-down and silting-up of the soil when wet with consequent loss in aeration and permeability. Secondly, a comparatively low moisture range over which the soil can be worked, i.e. a rapid transition from the hard cloddy to the adhesive state.

For measuring water stability the normal Yoder method of wet sieving was considered inadequate, as it really only measures "slaking," i.e., the break-down of dry aggregates on immersion in water. To simulate field conditions more closely, a modification of the Vilensky-McCalla falling drop method was used. A given size of natural air-dried aggregate was placed on a variable width slit and the number of drops of water required to break it up to pass the slit was measured. The aggregate itself is not immersed in water but is merely exposed to the effect of the falling drops. Based on fifty aggregates, both soils have a high-water stability, but for aggregates of 4-5 mm. and 1-2 mm. the arable soil was slightly superior. The method is apparently very sensitive, as preliminary tests on Barnfield plots gave three-fold differences between 4A and 10 in the amount of water required. The only disadvantage is that it is very tedious.

As the above method did not yield any large difference between the two fields, the stability of 1-2 mm. natural aggregates to wetting and drying was measured by using Childs' method of determining the suction-water content relationship of the inter-aggregate spaces. The interpretation of the resultant graphs was improved by determining the slope of the curves at 16.8 cm. suction, corresponding to Haines' determination of the maximum entry value for pores, thus eliminating the effect of the actual arrangement of the aggregates in the Büchner. On this basis the ley was superior to the arable. At the same time, two other samples from the Drayton farm were compared: one from each half of a field which had been half in ley and half in arable for three years. These showed up approximately the same difference between ley and arable, although their stabilities were lower than the previous ones. The method is accurate and could be easily developed into a routine test.

Finally, at the suggestion of M. B. Russell, the Yoder technique was used, but the wet sieving was continued for varying times and the weight retained on the sieve plotted against time. Russell found a linear relationship between log t and the weight retained, but this did not seem to apply to these soils. Since the break-up of aggregates on immersion in water takes place—due to compression of the air inside and to differential swelling—presumably after the time required to saturate the aggregate any further break-down is due to mechanical erosion.

For the second line of approach, the limited working range of the soil, the upper limit was determined by mechanically mixing powdered soil at increasing moisture contents and plotting the degree of aggregation. It was shown that aggregation suddenly commenced at 18 per cent moisture content and increased rapidly until the two soils attained a monolithic state at 24 per cent moisture content, the latter point being extraordinarily critical and much lower than the sticky point values of the two soils (about 35 per cent moisture content).

It was hoped to measure the lower working limit by determining the moisture content at which the cohesion of aggregates was sufficiently reduced to be broken up by a disc type harrow. A simple apparatus was made in which aggregates were crushed between two parallel plates. In the first experiment a highly significant difference in the load required to rupture 3-4 mm. air-dried aggregates was found, based on an average of twenty aggregates. This is the principal difference found between the two soils so far, but whether this will elucidate the very marked difference in structure visible in the field remains to be seen. Water stability does not seem to be an important factor, although up to the present only air-dry aggregates have been used, and it is possible that the variation of water stability with moisture content might yield interesting results.

Measurement of the volumes of solids, water and air in soils clods

The method introduced by Dr. E. W. Russell and modified by Dr. M. L. Puri has been further tested by Mr. W. W. Emerson. He has found it better to measure the volume of the water finally distilled from the clod under toluene than to run it off through a

tap and weigh it. An interim report has been prepared and is available on request. A paper describing the method is being prepared for publication.

Effect of temperature on soil moisture

During a two months' visit Dr. L. Cavazza made a preliminary study in which a soil clod taken from the field in such a way as to preserve its natural structure was subjected to temperature changes between 5° and 40°C. The clod rested on a sintered glass membrane through which water could be withdrawn from or given to the clod, the suction (pressure deficiency) of the water under the membrane being measured by a manometer. In one series of measurements the suction was adjusted as the temperature was changed so as to prevent the water content of the clod from altering. In a second series of measurements the suction was maintained constant and the water content allowed to change with temperature.

Surprisingly large temperature effects were observed, the interpretation of which is greatly complicated by the fact that the same amount of water when held on the clod develops a greater suction at a given temperature when it has cooled to that temperature than when it has warmed to it.

Field measurements of suction

Mr. E. M. Clegg has been testing a form of tensiometer designed to give rapid indication of the low suction values developed in soil above a water-table. This form of instrument may help to demonstrate whether or not land drainage is desirable. The temperature effects have proved to be very troublesome unless the sintered glass membrane is placed deep enough in the ground to be within the "capillary fringe" above the water-table. This may extend less than one foot above the water-table. In spite of this difficulty this method of investigation appears promising enough to be worth pursuing further.

Vapour pressures of aqueous solutions

Accurate measurement or control of aqueous vapour pressure is fundamental to much of the work on water in soils and plants and in the atmosphere. Values of the vapour pressures of NaCl solutions calculated from the E.M.F. values of concentration cells were provisionally adopted as the standard, in spite of small systematic differences that appeared to exist between these values and those obtained by direct measurement. In the course of a critical study of these discrepancies Mr. G. H. Cashen obtained, through the courtesy of John Hopkins University, microfilm copies of the theses of W. R. Norris and S. S. Negus which describe their very accurate direct measurements made under the direction of J. C. W. Frazer of the differences of vapour pressure between NaCl solutions of different concentrations. It emerged that through a defect in the thermometer used to adjust the temperatures of the thermostats these measurements were made at 19·94°C. and 24·94°C. and not at 20°C. and 25°C. as had appeared from the only published account of the work. Vapour pressures are so sensitive to temperature, that even ·06°C. is of importance in accurate work, and it is

very satisfactory to be able to report that there is, in reality, no serious discrepancy between these direct measurements and the E.M.F. measurements of Harned and Nims.

If we assume, as it seems we must, that the similar measurements of Lovelace, Frazer and Serase on KCl solutions were made at 19·94°C., and not at 20°C., their results are found to support the conclusion that satisfactory values for the vapour pressures of KCl solutions are obtained by combining the values provisionally adopted for NaCl with the concentrations of NaCl and KCl solutions of equal vapour pressure (isopiestic concentrations) which have been accurately determined by several workers. Distinctly different values are obtained by calculation from the available data for the E.M.F. values of KCl concentration cells, and these must be rejected.

Mr. Cashen has obtained further evidence pointing in the same direction by calculating from the heats of solution of several solutes in their saturated solutions and their temperature coefficients of solubility the rate of change of vapour pressure with concentration at saturation. Measurements of isopiestic concentrations enabled him to obtain the corresponding change with concentration of the vapour pressure of NaCl and KCl solutions. Again there is very satisfactory agreement with the NaCl standard but not with the KCl E.M.F. data.

We now feel that the values adopted for the vapour pressure of NaCl solutions must be very close to the truth, and we believe them to be a distinct improvement on tabulated values in current use. A detailed account of this work is in preparation, and we hope that the results will be useful in other laboratories.

Aluminium ions in acid soils

Mr. Taylor has been extending the work already done on the simpler ions $-Ca^{++}$, Mg^{++}, K^{+} and H^{+} to aluminium ions which are known to be present in acid soils. As a first step a study was made of the products of the reaction between $AlCl_3$ and $Ca(OH)_2$ at high dilution. He has shown that aluminium can exist in true solution at a concentration of 2×10^{-5} molar when the pH is as high as 5·3, the solution then containing both Al^{+++} and $AlOH^{++}$ ions, in proportions governed by an equilibrium constant which he has determined at three temperatures. The minimum solubility occurs at about pH 6, above which aluminium occurs in solution almost entirely as aluminate ions $-Al(OH)_4^-$.

When samples of an acid soil are shaken with solutions of $CaCl_2$ of concentrations ranging from M/100 to M/1,000, the concentrations of aluminium found in the filtrates do not fall off so much with decrease in the concentration of $CaCl_2$ as would be the case if all the aluminium in solution existed as triply charged ions. The proportion of $AlOH^{+}$ can be calculated from the pH, and is quite insufficient to account for the observed behaviour. It appears that much of the aluminium dissolved in the soil solution is not present as simple Al^{+++} or $AlOH^{++}$ ions, but as complex ions carrying one or two unit charges or even as uncharged molecules. Further tests are being made to verify this deduction and get further information about these complexes.

Equilibrium concentration of phosphate ions

Dr. H. C. Aslyng has shown that when a soil sample is shaken up with a dilute $CaCl_2$ solution, a small but definite concentration of phosphate ions is found in the solution after separation from the soil by filtration. The more dilute the $CaCl_2$ solution the greater is the phosphate concentration, and it has proved convenient to standardize the $CaCl_2$ concentration at M/100, which is about the upper limit of the salt concentration of natural soil solutions in normal soils and is strong enough to ensure flocculation of clay soils so that a clear filtrate is easily obtained for colorimetric estimation.

If soil samples are dried before they are brought in contact with the $CaCl_2$ solution higher phosphate concentrations are generally found than when the soil is examined fresh. Some soils are more sensitive in this respect than others, and the higher the temperature of drying the greater the disturbance. The ratio of soil to solution has only a small influence on the result : 25 gm. of soil in 50 ml. of solution are generally convenient.

Proof that we are dealing with a reversible equilibrium between the phosphate ions in solution and those " sorbed " on the soil particles has been obtained from physico-chemical studies in which it has been possible, on the one hand, to exchange the soil cations without altering the value of $pH + pH_2PO_4$ and, on the other hand, by adding lime to increase the pH without materially altering pH_2PO_4 in M/10 $CaCl_2$. The equilibrium concentrations found in the calcareous soils of Broadbalk and Hoosfield, which receive superphosphate, correspond with the solubility obtained by Bjerrum for the metastable calcium phosphate $Ca_4H(PO_4)_3.2H_2O$.

CHEMISTRY DEPARTMENT

By E. M. Crowther

Fertilizer Investigations

Phosphate fertilizers

For several years supplies of phosphate fertilizers in the United Kingdom have sufficed to meet a steadily increasing demand. Fertilizer prices were kept constant by subsidies as the prices of farm products and the cost of labour increased, and it was profitable to manure crops heavily. The prospects for continued expansion and intensification were, however, severely checked during 1950. The general fertilizer subsidies were reduced in 1950 and are to be removed in 1951, a subsidy on fertilizers for grassland taking their place. Severe cuts in the imports of sulphur and the likelihood of a continued world shortage of sulphur will require a critical re-examination of fertilizer policy, both nationally and on individual farms.

Restricted supplies of the standard fertilizers will have to be used more economically and efficiently by giving small quantities frequently in place of large ones occasionally. Ways must be found for making active phosphate fertilizers without using so much sulphuric acid. Wartime studies of the results of field experiments showed how individual crops and fields could be rationed to obtain the best returns. Under many common conditions rates of phosphate application on old arable land in fair condition, can be cut down without serious loss of crop. Several kinds of phosphate fertilizer without water-soluble phosphate can give results approaching those from superphosphate, at least on acid soil. On very acid soils in wet areas ground mineral phosphate often gives very good results, especially for swedes and grassland.

E. M. Crowther and G. W. Cooke have summarized, in a report to be published by the Ministry of Supply, the results of a series of field trials on silicophosphate, carried out in collaboration with the Advisory Chemists of the Ministry of Agriculture. The silicophosphate was prepared by the Building Research Station by heating phosphate rock with soda-ash, sand and steam in a rotary kiln furnace. Typical results are given below for the average of experiments in 1943 to 1946, mostly on acid soils chosen as likely to be deficient in readily available phosphate.

	Swedes tons/acre	Potatoes tons/acre	Growth of reseeded grass (visual scores)
Number of experiments	29	25	13
No phosphate	9·1	5·0	51
Superphosphate			
0.33 cwt. P_2O_5 per acre	13·3	7·5	104
0·66 cwt. P_2O_5 per acre	14·8	8·3	117
Silicophosphate			
0·5 cwt. P_2O_5 per acre	13·8	7·6	112

The two rates of application of superphosphate (a little less than 2 and 4 cwt. per acre) were deliberately kept low in the hope of obtaining crops in the steep and sensitive portion of the response

curves. Where, as in so many earlier experiments, different kinds of fertilizers have been compared at the heavy rates commonly recommended in demonstrations, similar yields do not necessarily mean that the fertilizers were equally effective but merely that each was being used extravagently. In the experiments summarized above, quite modest dressings sufficed to give good crops. On the average of 29 experiments on swedes and also of 25 experiments on potatoes, 2 cwt. superphosphate per acre increased yields by one half, and 4 cwt. superphosphate gave only small additional increases. Results of the same general pattern were obtained on reseeded grass. Even for sensitive crops there is little need for heavy dressings of phosphate fertilizer.

If halving the quantity of superphosphate makes only a small difference in the response of the crop, the relative values of two alternative forms of phosphate can be determined with confidence only from a large number of fairly precise experiments. The results of a few isolated experiments may be quite misleading.

In the above series of comparisons silicophosphate proved to be just as effective as superphosphate, on the basis of equal phosphorus, for swedes and reseeded grass but less efficient for potatoes. In a small number of experiments the silicophosphate appeared to be much less effective on cereals. Silicophosphate suitably used thus offers one possible way for economizing in sulphuric acid.

The results of field experiments on phosphate fertilizers are being summarized for publication, and new series of experiments are being planned in co-operation with the National Agricultural Advisory Service.

Fertilizer placement

Wartime experiments showed that superphosphate and compound fertilizers are used more efficiently by cereals when they are drilled with the seeds. The high initial concentration of plant nutrients near the roots favours early establishment and growth. Trials have been made with special experimental drills to see whether safe methods can be found for obtaining similar advantages for other crops, especially those in which the young seedlings are likely to be damaged by drilling the fertilizers in immediate contact with the seeds.

With potatoes planted in the furrows of ridged land side-band applications two inches from the sets had no advantage over the usual method of spreading fertilizer over the ridges before planting. Both of these methods were much superior to dressings broadcast before ridging. The rapidly increasing use of mechanical planters, working on the flat or planting into ridges, raises new questions, since these machines do not reproduce the relative positions of sets and fertilizers obtained by broadcasting fertilizer over ridged land. Discussions with the National Institute of Agricultural Engineering led to their developing a new experimental potato planter fitted with a fertilizer attachment, capable of applying known amounts of fertilizer in prescribed positions.

In continuing their investigations on fertilizer placement, G. W. Cooke and F. V. Widdowson obtained advantages from placing fertilizers in bands about two inches to the side of seeds of

several quickly growing and shallow-rooting crops, but there were no similar advantages for deeply-rooting crops with long growing seasons.

Ten experiments on sugar beet were carried out in 1949, a drought year. Granular PK fertilizer containing 16 per cent P_2O_5 and 13 per cent K_2O was applied by several methods, nitrogen fertilizer being broadcast uniformly over all plots. Germination and plant establishment was not damaged by PK fertilizer placed two inches to the side of the seed. Broadcast PK fertilizer increased yields of sugar significantly at three centres. There were no significant differences between the yields given by placed and broadcast fertilizer.

The results of the 1949 experiments on sugar beet confirm those of earlier years; there is no advantage from placing a full dressing of fertilizer beside the seed in districts where the crop is normally grown, except that labour is saved in applying the fertilizer. The results of experiments over three years, of which two were very dry, are summarized below:

	1947	1948	1949
No. of experiments	8	13	10
Fertilizer tested			
Per cent N	9·0	9·0	0·0
Per cent P_2O_5	7·5	7·5	16·0
Per cent K_2O	4·5	4·5	13·4
Amount, cwt./acre	6·8	7·5	5·2
Mean unmanured yields			
Sugar cwt./acre	44·3	39·6	37·0
Tops tons/acre	7·7	9·9	12·6
Mean increases in yield from broadcast fertilizer			
Sugar cwt./acre	2·0	4·8	1·1
Tops tons/acre	1·1	2·8	0·9
Mean increase in yield from placing over broadcasting			
Sugar cwt./acre	—1·0	0·4	0·0
Tops tons/acre	0·5	0·1	—0·2

Experiments were carried out in 1950 on winter beans, spring beans, threshed peas and on peas picked when green. Granular fertilizer containing 14 per cent P_2O_5 and 14 per cent K_2O was applied by several methods. Broadcast fertilizer was applied at two stages in the preparation of the seedbed. Early dressings on the ploughed land were worked in deeply by the cultivations given to prepare the seedbed. Late dressings were applied to the seedbed and harrowed in shallowly. Placed fertilizer was applied in a single band two inches to the side of the seed and three inches below the soil surface. Tests were also made of half the fertilizer placed beside the seed and half broadcast (either early or late).

For winter and spring beans and for green peas early broadcasting gave higher yields than late dressings. For all of these

crops placed fertilizer gave higher average yields than broadcast fertilizer. For both types of beans and for green peas approximately 2·5 cwt. per acre of fertilizer placed beside the seed gave maximum yields which were higher than the yields given by double the quantity of broadcast fertilizer. There was no advantage for any crop from broadcasting half the dressing and placing the remainder beside the seed. Results over several seasons will be summarized when the 1951 experiments are completed.

Experiments on carrots, kale and red beet compared broadcast dressings of a granular phosphate-potash fertilizer with the same fertilizer placed two inches to the side of the seed and three inches below the soil surface. Nitrogen fertilizer was broadcast uniformly over all the plots.

In two experiments on carrots broadcast fertilizer increased yields significantly while placed fertilizer had no effect. The responses to fertilizer were small and irregular in two other experiments on carrots.

In a single experiment on kale placing fertilizer gave higher yields than broadcasting. Both methods of applying fertilizer for red beet gave similar increases in yield.

National Compound Fertilizer No. 2 (9 per cent N, 7 per cent P_2O_5, 7 per cent K_2O), was tested in one experiment on spinach. Placing fertilizer two inches to the side of the seed increased yields significantly; broadcast fertilizer gave only a small increase in yield.

Rates of action of nitrogen fertilizer

Investigations briefly described in the 1949 Report were extended in 1950, R. G. Warren being responsible for preparing special materials and analysing the crops, E. H. Cooke for carrying out pot experiments on repeatedly cut perennial rye grass and B. Benzian for the trials in forest nurseries and forests. In the pot experiments factorial combinations of graded dressings of urea applied at appropriate times throughout the season served as standards, together with coarse (5–6 mm.) and fine (1–2 mm.) fractions of crushed hoof. Formalized casein, a plastic waste, again gave outstanding results, acting fairly rapidly and maintaining good growth throughout the season and well on into the winter, when the effects of many other materials had been exhausted. Some of a series of urea-formaldehyde condensation products prepared in industrial research laboratories acted much more rapidly, giving results closely akin to those from fine hoof. Attempts to slow down the action of hoof by inactivating it with formaldehyde, copper salts or nitrous acid were so successful that the experiments will have to be continued into 1951 to decide whether the very slow liberation of available nitrogen will continue long enough to allow a high total recovery. Further work on these lines may make it possible to develop, for experimental purposes at least, a set of nitrogen fertilizers of known rates of action. A danger in relying on organic wastes for slowly available nitrogen was illustrated in this experiment by a commercial sample of meat meal which gave only a very small proportion of rapidly available nitrogen with negligible amounts of slowly available nitrogen.

The rates of action of fragments of organic materials were appreciably reduced by coating them with aminoplastics but similar trials with granular and other inorganic fertilizers were less successful. It appeared that the salts diffused out rapidly or, alternatively, that the coated granules soon absorbed water and burst.

Nutrition Problems in Forest Nurseries

Investigations in collaboration with the Forestry Commission, reviewed over the period 1945 to 1949 in the Rothamsted Report for 1949, were continued by E. M. Crowther, R. G. Warren and B. Benzian. In the wet season of 1950 there were much more striking contrasts and responses to treatments than had been obtained in the three preceding years.

Sitka spruce seedlings showed large responses to each of the major nutrients in experiments on very acid soils, but in some of these experiments composts well supplied with nitrogen, phosphorus and potassium gave better results than inorganic fertilizers. It appeared that the fertilizer nitrogen applied in the seedbeds in spring and in an early summer top-dressing had been leached out of the surface soil during the very wet summer and autumn before the period of most active growth.

In the neutral or slightly acid soils of old nurseries Sitka spruce seedlings generally make very poor growth, even when well manured with compost or fertilizers. In 1950 at several nurseries there were very striking responses on such soils to acidification in previous years by ammonium sulphate or sulphur. By contrast, the residual effects of aluminum sulphate were small. In one experiment with repeated dressings of nitrogen fertilizers on the same plots for seeds sown in 1949 and again in 1950, there were only moderate gains in 1950 from "Nitrochalk" but very good ones from equivalent amounts of ammonium sulphate. In the drought of 1949, when nitrogen fertilizers were generally ineffective, neither material did any harm. The repeated dressings of ammonium sulphate appear to provide a safe method of supplying available nitrogen and at the same time acidifying the soil. If this kind of result can be repeated under other conditions it may offer a simple practical remedy for an acute example of "soil sickness."

Steam and formalin treatments of the soil some weeks before sowing again gave dramatic improvements, the boundaries between plots showing very sharp contrasts. At four nurseries experiments on different amounts of formalin gave response curves closely akin to those for plant nutrients on highly deficient soils. It is not yet possible to offer an adequate interpretation of "partial sterilization" by steam and formalin. In addition to killing many classes of microorganisms both treatments greatly increase the supply of available energy, as is shown by a rapid increase in the production of carbon dioxide and ammonia in incubated soils. On the treated plots the ammonia contents of the soils remained higher throughout the season and nitrification in incubated soils was checked.

The hypothesis that partial sterilization depends on the elimination of soil fungi harmful to or competing with the roots of the conifer seedlings was examined in several nurseries and in series of

pot experiments by E. H. Cooke. A wide variety of fungicides and two antibiotics were added to the soil or applied as seed-dressings. Several of these materials reduced early deaths by "damping-off" in the pot experiments, and others damaged the seedlings, especially at high rates of application. None of them, however, approached steam or formalin in their general effects on growth. Such results in a good growing season indicate that the control of soil fungi may be a relatively unimportant factor in the effects of steam, formalin and acidification in improving the growth of Sitka spruce seedlings on the so-called "Sitka-sick soils." Many of the observations already made could be interpreted on the hypothesis that conifer seedlings utilize ammonia in the soil more efficiently than nitrate, but the results of further investigations in the Microbiology and Chemistry departments must be awaited before this hypothesis can be adequately tested.

In several experiments on neutral or slightly acid nurseries Sitka spruce responded well to superphosphate on plots which had received formalin but not on plots without formalin. An indication of the complexity of formalin effects was given in two experiments on very acid nurseries, one on heathland and the other in a clearing in a conifer forest. On plots without formalin inorganic fertilizers gave better plants than compost. Previous treatment with formalin greatly improved growth on the compost plots and had no effect on the fertilizer plots. The appearance of the plants suggested that those with formalin and compost received large quantities of available nitrogen late in the season. Presumably the formalin retarded the breakdown of proteins from the compost in much the same way as in the pot experiment on hoof described in the previous section of this report.

Soil Investigations

Soil Organic matter

J. M. Bremner's earlier work on the amino-acid composition of the protein material in soil was completed and prepared for publication. Ten soil samples, differing greatly in pH value, organic matter content and cultural history, were examined, the amino-acid composition of their acid hydrolysates being studied by paper partition chromatography. The following twenty amino-acids were found in every hydrolysate : phenylalanine, leucine, isoleucine, valine, alanine, glycine, threonine, serine, aspartic acid, glutamic acid, lysine, arginine, histidine, proline, hydroxyproline, $\alpha\epsilon$–diaminopimelic acid, α–amino-n-butyric acid, β–alanine, γ–amino-butyric acid and tyrosine. Methionine sulphoxide and glucosamine were found in most of the hydrolysates, but cystine, methionine and tryptophan could not be detected. D-amino-acids were detected in the hydrolysates but the small amounts found could have arisen by racemization during hydrolysis. No free amino-acids could be detected in any of the soils studied. The detection of glucosamine, serine and threonine in the hydrolysates confirmed previous evidence that 2-amino sugars and hydroxy-amino-acids occur in soil.

Comparison of the strengths of the spots on the chromatograms indicated that the protein materials in the ten soils examined were similar in amino-acid composition.

During the course of the work described above it was noted that alkaline hydrolysates of soil contained greater amounts of glycine, alanine and α-amino-n-butyric acid than did acid hydrolysates. This observation led to an investigation of the effect of hot alkali (NaOH and $Ba(OH)_2$) on various amino-acids. Results so far obtained show that under the conditions commonly employed for the hydrolysis of proteins with alkali cystine and cysteine yield alanine ; serine yields glycine and alanine ; threonine yields glycine and α-amino-n-butyric acid. An attempt is now being made to determine the extent of these dismutation reactions under various conditions.

A review of recent work on the organic phosphorus and nitrogen of soil and on the uronic fraction of soil organic matter was prepared for publication.

Studies in conjunction with R. H. Kenten of the Biochemistry department on the amino-acid metabolism of soil using the perfusion technique were temporarily abandoned owing to the practical difficulties encountered. The experience gained, however, made it obvious that there was need of a rapid method of identifying small amounts of amines formed by decarboxylation of amino-acids, and some progress has been achieved in the application of paper partition chromatography to this problem. The chromatographic behaviour of a large number of biologically important amines in various solvents has been studied and many useful separations have been achieved.

Soil phosphorus

J. B. Rickson has used the radioactive tracer technique in studying the behaviour of soil and other phosphates. When a solution of a phosphate labelled with radioactive phosphorus is added to soil the changes in the amounts of P^{31} and P^{32} can be used to estimate what fraction of the total phosphorus of the soil is capable of undergoing exchange. Soils with contrasted manuring for over a century in Broadbalk field were compared. In one with superphosphate annually about one-fifth of the total phosphorus was exchangeable. In one without added phosphate for the same period the amount of exchangeable phosphorus was negligible.

In similar experiments on ground crystalline fluorapatite the exchangeable phosphorus varied from 0·05 to 0·4 per cent of the total phosphorus according to the size of the particles. For laboratory preparations the following values were obtained: dicalcium phosphate 1·7 per cent, aged hydroxyapatite 1·5 per cent, freshly prepared hydroxyapatite 8·1 per cent. The " exchangeable " phosphorus determined in this way depends to some extent on the particle size but also, to a lesser degree, on the time allowed for the exchange. There is evidence that the " exchangeable " phosphorus is not confined to the surface of the particles.

In a number of experiments covering a range of concentrations of P^{31} and P^{32}, it was shown that all the phosphate adsorbed on a synthetic anion exchange resin was readily exchangeable.

Fluorine in soils

Work briefly summarized in the Annual Report for 1948 has been continued by J. B. Rickson. Only about 20-40 per cent of the

fluorine added in superphosphate over a long period of years is retained in the soil. The increase by manuring is small in comparison with the amounts naturally present in soils. For soils with from 14 to 24 parts fluorine per million the increases by manuring for about 50 years were from 3 to 8 parts fluorine per million.

Soil manganese

In continuing her work on factors influencing the availability of manganese in soils, S. G. Heintze tested in pot experiments the effects of a number of different ways of adding manganese to a skirtland fen soil before sowing oats. The soil was acutely deficient in available manganese and no treatment prevented the appearance of grey-speck symptoms. Copper deficiency was also visible in the young leaves of tillers for most of the treatments.

All additions of manganese significantly increased yields of grain. Although few of the differences between alternative forms were significant the best grain yields from manganese compounds were from permanganate solution, manganese dioxide and manganese sulphate crystals coated with an aminoplastic.

Analytical

Exhaustion Land, Hoosfield

An account was given in the Rothamsted Report for 1949 of the history of plots which showed in the barley crop of that year most striking residual benefits from farmyard manure and superphosphate applied before 1901. The site had been used from 1856 to 1874 for a manurial experiment on continuous wheat and from 1876 to 1901 for one on continuous potatoes. Since then the land has been cropped mostly with cereals, without fertilizers until 1939 and subsequently with cereals receiving a liberal dressing of ammonium sulphate on all plots. The 1949 yields of barley grain and straw are given below together with analytical data by R. G. Warren for the crops and soils. Several plots have been averaged to give groups with no added phosphorus from 1856 to 1901, with superphosphate from 1856 to 1901, and with farmyard manure from 1876 to 1901 (superphosphate was given with the farmyard manure from 1876 to 1882).

Plots	Manuring to 1901	1949 *Barley crop* (*cwt./acre*) Grain	Straw	P_2O_5 in total crop
1, 2	None	8·8	10·4	0·047
5, 6	Nitrogen only ..	10·8	13·9	0·056
7, 8, 9, 10	Superphosphate ..	25·3	24·8	0·155
3, 4	Farmyard manure ..	26·4	24·8	0·165

Plots	Manuring to 1901	1949 *soil analyses* pH	nitrogen per cent total	P_2O_5, mg/100g Readily soluble
1, 2	None	7·2	0·110	1
5, 6	Nitrogen only ..	6·8	0·112	1
7, 8, 9, 10	Superphosphate ..	7·2	0·112	6
3, 4	Farmyard manure ..	7·2	0·138	6

Plots which had received phosphorus before 1901 in farmyard manure or in superphosphate gave nearly three times as much grain and twice as much straw as plots without any added phosphorus. The crops on plots with farmyard manure or superphosphate residues contained over three times as much phosphoric acid as those without added phosphorus before 1901.

The manurial residues were clearly shown by soil analyses. The contrasts were relatively great for readily soluble phosphoric acid (extracted by leaching with 0·5 M acetic acid). The residues of farmyard manure increased the soil nitrogen and organic matter by one quarter. The prolonged residual effect of heavy dressings of farmyard manure is also illustrated in the continuous barley plots in the same field.

Plot	Manure	*Nitrogen per cent of soil*
1–0	Unmanured since 1852	0·100
7–1	Farmyard manure 1852-1871, then unmanured	0·147
7–2	Farmyard manure annually since 1852 ..	0·266

Soil analyses on unreplicated plots are always subject to uncertainties through the risk of inherent irregularities, but the consistency of these two sets of plots gives support to the conclusion drawn from other investigations that farmyard manure leaves some very inert organic residues. The fact that superphosphate and farmyard manure have similar residual effects on crops and also on readily soluble soil phosphorus suggests that much of the residual benefit from farmyard manure is to be ascribed to its inorganic constituents. These results suggest that the conventional low estimates of the residual value of phosphate fertilizers and the emphasis placed on phosphate fixation may derive in part from the failure of ordinary field experiments to measure small benefits maintained over long periods.

Spectrographic analyses

In the Lundegardh flame method of spectrographic analysis using a medium quartz spectrograph, H. A. Smith is attempting to replace the usual photographic record by direct photometry. An exit slit in the focal plane of the camera lens isolates the required line, the intensity of which is measured by a photo-multiplier tube with a suitable amplifier. This method may have advantages over direct flame photometry in that it allows measurements to be made in the ultraviolet, which is particularly convenient for manganese and magnesium. The sensitivity so far attained promises to compare favourably with the photographic method.

GENERAL

E. M. Crowther, S. G. Heintze, J. M. Bremner, and J. B. Rickson attended the Fourth International Congress of Soil Science at Amsterdam in July, 1950. E. M. Crowther was Chairman of the Soil Fertility Section.

PEDOLOGY DEPARTMENT

By A. Muir

During the year Mr. J. R. Butler was appointed to the spectrographic section. Mr. K. Norrish of the Waite Institute who has come for two years' study and Mr. J. Garcia Vincente from Madrid, are carrying out X-ray studies on soils from their respective countries. Dr. E. M. Chenery completed his period of research under the Colonial Development and Welfare Research Scheme and has now taken up a post in Uganda.

Two members of the department (Dr. D. M. C. MacEwan and G. Brown) have between them taken a considerable share in the compilation of the Clay Minerals Group monograph on " The X-ray Identification and Structure of Clay Minerals," which is to appear in 1951.

Weathering of Rocks and Minerals

The study of the weathering of the crystalline rocks of the Malvern complex is now essentially complete and has shown strikingly the effect of parent bed-rock in determining the secondary products, i.e. the mineralogical composition of the clays of the derived soils. The results show the dominance of clay minerals of the chlorite-vermiculite crystallization associated with the ultrabasic rocks rich in hornblende and biotite, and of an illitic clay mineral with the granitic rocks. In the " Ivy Scar Rock " (a granophyric quartz diorite) of intermediate composition both types of clay minerals are present in the soil clay. The other crystalline constituents of the soil clays are kaolin and quartz, which are particularly associated with the more acid rocks. Iron and aluminium oxides are present in all the clays, but are mainly in the amorphous state.

A similar comparative study of the mineralogical characteristics of soils from the Gold Coast derived from acid and basic rocks has been started.

Clay Mineral Studies

Techniques

There has been considerable call on the X-ray apparatus for use as an auxiliary to petrological and other studies. It has thus been necessary to give much attention to the question of reducing exposure times for X-ray photographs. The question has been approached from several different directions.

(1) The use of a larger tube current with the usual size of focus is precluded by the rate of heat dissipation at the anode, but with the slit collimation we employ it has been found that perfectly sharp photographs can be obtained from a much larger focus than usual, which permits passage of a larger current and hence shorter exposures.

(2) Substitution of detachable windows sealed with rubber O-rings enables the filter material, which is in any case necessary, to be used as a window instead of aluminium and so eliminates

absorption from this source. The camera windows have been replaced by 0·3 mm. polythene, which, unlike cellophane, seems to be unaffected by X-rays.

(3) Experiments have been made with a camera slit system made of metallized glass plates. Such a system reflects X-rays which strike it at a narrow angle and so gives an enhanced intensity. The system we use gives a gain of about 2x, but appears to give rather broader lines than the ordinary collimating system, which may be due to the poor optical quality of the glass used, together with inaccuracies in assembly.

(4) The use of Zelger's copper intensifier on the film gives an improvement in contrast as well as intensity. The complications of the procedure, however, are such that it will not be applied unless a number of films are processed together, or it is essential to have an exposure of minimum length.

The total reduction of exposure time by a factor of 6 may be achieved by these methods, and it is now possible to obtain a well-exposed photograph in 10 minutes.

Quantitative determination of clay minerals

Preliminary calculations have been made on a method based on the use of oriented aggregates for the accurate determination of clay minerals in mixtures by X-rays, and experiments are being carried out. The problem is not a simple one, but this method seems to hold out considerable hope of an eventual solution. It has been described in a preliminary communication to the Clay Minerals Group. Arising partly out of this, extensive calculations have been made on the effects of orientation and absorption on the intensities of X-ray reflections from oriented aggregates of clays.

Clay mineralogy of rocks and soils

(1) In collaboration with W. N. Croft of the Imperial Institute an investigation has been made of the clay mineral content of Devonian siltstones from North Wales. The problem was to find if the break between Upper and Lower Devonian (several million years) was reflected in the mineral composition. A break was found, there being chloritic material present in the Lower Devonian which was almost absent in the Upper Devonian. A series of Brecon siltstones is now being examined to see if a similar break can be traced.

(2) A number of soils from the Kongwa groundnut area have been examined to see if some indication could be got of the reason for the strong compaction occurring after rain. The general properties of the soils that show their characteristics, the red loam in particular, correspond to those of comparable soils from other parts of Africa, i.e., low silt content, low base exchange capacity. The clay minerals in the red loam and upland pallid soils proved to consist mainly of halloysite with a little mica, quartz and iron oxides. The dark valley soil clay consisted mainly of mica with some halloysite as accessory. The sand fractions consisted almost entirely of angular quartz fragments. There is nothing in the results to suggest that there is anything inherently peculiar about

the Kongwa soils, but samples from other groundnut areas are now available so that the investigation can be extended.

(3) A wide range of soil clays from Syria have been studied with interesting results. It was found that the mineral attapulgite was a common and sometimes abundant constituent of the soils derived from the sedimentary rocks of the desert. The *terra rossa* soils of the Mediterranean coastal area contained mainly a "mellorsitic" type of clay mineral. The clay minerals of the basalt soils are apparently connected with the degree of crystallinity of the rock; the highly crystalline rocks yield halloysite on weathering, whereas the glassy types of basalt give beidellite.

(4) The department has now a considerable collection of bentonites, and alleged bentonites, from various sources, as well as other clay materials, and X-ray photographs have been taken with a view to establishing a series of standard patterns likely to be of use in dealing with soil clays.

The examination of a series of Punjab clays from Dr. J. N. Mukherjee showed that some were kaolinites of quite exceptional purity, the others containing a montmorillonite impurity.

Among other materials examined by X-ray methods were soil clays from Uganda, Iraq, Persia and Ireland.

Location of the sorbed ions and molecules in montmorillonoids

This investigation has now been completed for both montmorillonite, the dioctahedral montmorillonoid, and hectorite, the trioctahedral member. The results for both of these support the Hofmann structure for the minerals and show that the exchangeable cations take up a position midway between the inorganic layers of the mineral in their glycerol complexes.

Complexes of montmorillonoid clays with proteins

Using oriented flakes of clay particles ($< 1\mu$) a new phenomenon has been observed: one-, two- and four-layer complexes have been detected with gelatin, edestin and pepsin suspensions according to the concentration and pH of the suspension: each layer has a thickness of 4.3 to 4.5 Å, which corresponds very closely to the calculated and directly observed thickness of single polypeptide chains in proteins. This implies a competition between the surface energy of the inter-lamellar spaces of montmorillonite and the lattice energy of the hydrated protein crystals. Furthermore, the most stable two- and four-layer complexes are formed at nearly 2 pH units below the pI of the protein, which strongly suggests the mechanism of proton transfer being necessary for these complexes.

Complexes of montmorillonoids and pyridine

A systematic investigation of the interaction of pyridine and other polar molecules with montmorillonite is in progress. Three main methods are being used. First the measurement of the sorption isotherms in the vapour and the liquid phases. Secondly, the study of the resultant complexes by X-ray diffraction and in certain favourable cases the application of one dimensional Fourier synthesis.

Thirdly, the use of the differential thermal method to study the evaporation of the sorbed material.

The results so far obtained indicate that the sorption isotherm of pyridine is dependent on the water content of the system, the nature of the base exchange ion in montmorillonite, and the previous heat treatment of the mineral.

Several other complexes likely to be of interest have been examined by X-ray diffraction. The blue and green colours formed by certain amines, notably dimethylaniline, with montmorillonite are being investigated. Results suggest that the colour formation in independent of the extent of interlaminar sorption.

Autunite

The mineral autunite, a calcium uranyl phosphate $Ca(UO_2)_2(PO_4)_2 \cdot n\ H_2O$ is a layer type mineral which shows reversible hydration properties between the states $Ca(UO_2)_2(PO_4)_2.10H_2O$ called autunite and $Ca(UO_2)_2(PO_4)_2.8H_2O$ called meta-autunite-1. The spacing of autunite is 10·32 Å and of meta-autunite-1 8·42 Å. The structure of the layers of oxygen atoms in autunite is similar to the structure of montmorillonite suggested by Edelman. It was thought that the autunite might be made to expand with organic liquids such as glycerol in the same way as montmorillonite.

The mineral was therefore synthesized and various treatments were tried, either adding the organic liquid to the freshly prepared autunite or precipitating the autunite in the presence of the organic liquids. No expansion was shown in any case. In fact, most of the treatments merely dehydrated autunite (the $10H_2O$ state) to meta-autunite-1 (the $8H_2O$ state). These changes were all followed by means of X-ray photographs.

Spectrographic Work

Work has been continued on the quantitative determination of molybdenum in soils and methods have been studied for other elements. The Mannkopff spectrograph has been found suitable for the quantitative estimation of potassium in solid specimens. Quantitative estimations have also been made of the major elements (i.e. Al, Ca, Fe, K, Mg, Mn, Na) in minerals, rocks and plant ashes. In addition, semi-quantitative methods are in use for about thirty minor elements.

The geochemistry of clays and soils is being investigated by these methods and it is hoped eventually to supplement the results by micro-chemical determinations of, more especially, zinc.

In the determination of exchangeable cations in soils, an alternative has been adopted by several workers to the standard method of leaching the soil on a filter with successive portions of ammonium acetate. This consists of allowing the solution to percolate through the soil in an automatic apparatus. The method is being investigated and an apparatus has been devised which is considerably simpler in design than some that have been described. The results obtained are in good agreement with those obtained by the leaching method and it is hoped to adopt the method for routine use.

Gleying in Soils

As reported previously, it has been found possible to induce gleying artificially in soil material by the action of anaerobically fermenting plant material. Under these conditions ferric oxide undergoes extensive solution and reduction, leaving an essentially iron-free residue. In this respect the laboratory experiments do not suggest a close parallel with the natural process since such analytical data as are available in the literature suggest that, in the field, gleying does not result in a marked diminution of the total iron content. However, it has been found that ferric oxide, either alone or as present in soil, has the property of abstracting ferrous iron from solution in an irreversible manner ; if the ferric oxide with its associated " fixed " ferrous iron is completely dissolved in acid it is found that little or none of the " fixed " iron is present in the ferrous state. It is suggested that the explanation of this is as follows : an initial adsorption of ferrous iron as the ferric oxide takes place, and in the adsorbed state the Fe^{2+} is sufficiently readily oxidised for this to be effected rapidly by dissolved oxygen in the system. It seems probable that this phenomenon is responsible for the differences between the laboratory and natural processes mentioned above.

It has been demonstrated that gleying is not necessarily caused by direct microbial action ; by treating a clay suspension with a fermented grass extract under sterile, anaerobic conditions, a gleying action is produced which, although less extensive than in the fermentation experiments, is nevertheless appreciable.

Extracts of fermented grass have been shown to cause an almost instantaneous reduction of dissolved ferric iron ; determination of the ferric-reducing capacities of such extracts gives theoretical values for the extent of gleying action which exceed the experimental results by a factor of 3 to 4. This, it is felt, indicates that the rate-determining stage in the overall process of solution and reduction is the initial solution of ferric oxide to give soluble ferric compounds, reduction of which takes place almost immediately.

Fermentation of grass in the presence of ferric oxide gives solutions in which the iron appears to be present entirely as complex ferrous compounds. More than one type of complex combination appears to be involved. Part of the iron is readily precipitated by atmospheric oxidation of the solution, or by an increase in the pH ; the iron remaining in solutions is not precipitated even after prolonged exposure to the air at pH9, and under these conditions oxidation of the Fe^{2+} is so slow that it is not possible at present to say with certainty whether oxidation does indeed take place.

SOIL MICROBIOLOGY DEPARTMENT

By H. G. Thornton

Effect of Partial Sterilization in the Field

During this season co-operation was continued with the Chemistry department on the effects of partial sterilization of nursery beds at Ampthill. The treatments studied were steaming and application of formalin. Some of the plots examined were treated in the spring of 1949 and others in the spring of 1950. The micropopulations of treated and control plots were surveyed at intervals. Miss L. M. Crump and Mr. P. C. T. Jones dealing with bacteria, Dr. J. E. Brind with types of fungi, while Dr. B. N. Singh made counts of the numbers of amoebae. The survey has shown remarkable differences related to treatment, in the numbers of the main groups of micro-organisms. There have also been differences due to the appearance on the treated plots of specific types of organisms. Those differences are unexpectedly persistent ; some are still found 18 months after the partial sterilization. This survey suggests several promising lines for further work in connection with partial sterilization.

Actinomycetes antibiotic against fungi

Fundamental knowledge of the conditions under which actinomycetes will grow and produce antibiotic secretions, and under which these secretions will remain active, is essential before one can hope to make practical use in the soil, of actinomycete species that show antibiotic activity on plates. Mr. F. A. Skinner has continued to study the action of certain actinomycete species of the genus Streptomyces in inhibiting the growth of *Fusarium culmorum*, and has extended this study to a number of other soil fungi that are also antagonized by actinomycetes. He has developed a method of standardizing the size of actinomycete colonies thus improving the accuracy with which antagonistic effects on agar plates can be measured. A description of this method has been published. Antagonism can usually be observed in a variety of media having a wide range of C/N ratio and differing greatly in sources of carbon and nitrogen. Actinomycetes will inhibit *Fusarium culmorum* and other soil fungi on media whose low level of nutrients approaches that of soil. This suggests that they may also produce antibiotic substances in soil. Antagonism on agar plates can, however, be prevented by the inclusion of adsorbing material, such as bentonite, in the media, so that it is possible that the antibiotic substances may also be rendered ineffective by the clay colloids of soil. The effects of other factors in the soil environment are being studied.

Strong inhibition of *F. culmorum* by actinomycetes has been found in sand culture, and tests have been made to find the best way to sample these cultures and to estimate the amount of fungal growth. The extension of this research into the soil itself requires a method for ascertaining the condition (whether as spores or mycelium) of actinomycetes in the soil studied. A method based on the effect of mechanical shaking with sand has been devised which shows considerable promise. An account has been published.

Nitrification

The very special nutrient media alleged to be necessary for the growth of *Nitrosomonas in vitro* contrast so evidently with the ease and varied conditions under which nitrification occurs in nature, as to suggest serious gaps in our knowledge of the microbiology of this process. Dr. Jane Meiklejohn has investigated *Nitrosomonas* from two points of view, its tolerance for glucose and its need for traces of metals. Glucose, when sterilized by autoclaving, produces a substance very toxic to the organism, but when sterilized by filtration glucose was not toxic up to a concentration of 0.02 M. When glucose was added to a mixed culture of *Nitrosomonas* contaminated with other bacteria, however, less nitrification was observed presumably owing to the competitive growth of contaminants.

Nitrosomonas has been found to need traces of iron, 0.6 mg per litre being an adequate dose. In an iron deficient medium, if provided with sufficient copper and manganese, it will oxidise ammonia after a considerable delay suggestive of adaptation.

Dr. Meiklejohn has obtained a pure isolate of the organism *Nitrobacter* whose physiology is being studied.

Myxobacteria

Dr. B. N. Singh has isolated from soil a species of the little known genus *Melittangium* which is unusual in producing stalked sporangia; this organism like *Myxococcus* feeds on Eubacteria by producing lytic secretions. Its life cycle and food requirements are under investigation.

Soil Amoebae—their identification and classification

In studies concerning the ecology of soil amoebae and their influence on bacteria, the correct identification of species is of importance because of the different behaviour of different species.

The most useful diagnostic character seems to be the type of nuclear division, but difficulty in obtaining all the normal stages of division has led to much confusion. Dr. B. N. Singh has developed a simple method for culturing soil amoebae on microscope slides or covers so as to obtain numerous dividing nuclei, which he has then treated with specific chromatin stains. He has applied this method in a range of species. From these observations he is proposing a simplified classification of the amoebae, based on the type of nuclear division, which should aid identification of these organisms.

Miss L. M. Crump is investigating the cultural habits and behaviour of the dominant soil amoebae found in Rothamsted soils, as these effect their ecological relationships and are in some cases valuable aids to identification. The factors influencing excystment, which have considerable ecological importance, are included in this study.

Mycorrhizal association in clover

The very common occurrence of the endotrophic mycorrhizal fungus, *Rhizophagus*, in clover and in wheat makes it important to

obtain definite evidence as to whether this association confers any benefit at all on the host plant.

The most direct way to do this would be to isolate the fungus and then grow host plants, some supplied with the fungus and some not. No one, however, has as yet succeeded in isolating the fungus and causing it to grow appreciably *in vitro*.

Dr. Janet Brind has therefore attempted a different method for obtaining clover plants some with and some without *Rhizophagus* under otherwise similar conditions. A suspension of fresh soil known to contain this fungus was serially diluted and sets of replicate pots containing sterilized sand sown with red clover were supplied with different dilutions, in the hope that at a suitable dilution, some replicate pots would receive the fungus and others would not.

In a preliminary experiment the fungus was found to be present at dilutions of 1/100 and lower, but absent at 1/1000, and within one dilution pots could be found with and without infection by *Rhizophagus*.

A third experiment using four dilutions between 1/5 and 1/500 was successful in giving infection of approximately half the pots (10) at the lowest dilution. Dry weights of the infected plants showed no significant difference from those of uninfected plants on the comparatively small number of pots available for comparison.

Nodule bacteria (*Rhizobium*) *from clover*

Previous work has shown the importance in legume inoculation of selecting strains of Rhizobium for use, that are able to grow well in the root surroundings of the crop and to produce a satisfactory infection. This is especially important where it is hoped to replace ineffective strains naturally present in the soil by more effective strains. Field experiments have shown that it is possible to inoculate a clover crop with a suitably chosen strain and to obtain a high percentage of nodules containing this inoculant strain, even in soil containing numerous "wild" strains of clover Rhizobium. So that where the soil contains numerous ineffective strains it should be possible to replace these with an effective inoculant strain. Success here requires the selection of strains that are both high in their effectivity towards the host plant and also in their ability to compete in the soil particularly against ineffective strains. Dr. Janina Kleczkowska has made pot experiments designed to select strains of clover Rhizobium combining these characters. The work is in progress.

Rhizobium bacteriophages

The investigation of these bacteriophages has been continued. Using one strain, Drs. J. and A. Kleczkowski have found that a single phage particle can initiate a plaque on solid medium or multiply in a liquid bacterial culture, but that not all particles normally succeed in doing either. The chance of success depends on the condition of the liquid bacterial culture inoculated with phage or used for plating. It is possible that in optimal conditions every phage particle will multiply to produce a plaque but there is no evidence for this.

Root secretions

Experimental work by Dr. P. S. Nutman during the year has been directed mainly to a study of the mutual interference between plants sharing the same root space, noted in a previous report. The suppression of nodule formation on one plant by the presence of another growing with it in the same culture vessel occurs under very diverse conditions and does not appear to be open to explanation in terms of competition for nutrients, light, or carbon-dioxide. Thus a completely resistent clover plant, or a plant responding ineffectively to nitrogen fixation, limits the infection on a companion plant to the same degree as a normally effectively responding plant making full demands on the nutrients and space available.

Experiments on the influence of the volume of the root medium and on replanting suggested that plant interaction may be due to the production of inhibitory substances from the root. Below a volume of about 10 cc. per plant a strict proportionality obtained between the numbers of nodules formed per plant and the volume of the medium. Replanting experiments show that the number of nodules developing on a test plant is related to the number of plantings previously made in the same medium. If the roots of the first crop are left *in situ* and only the tops removed, there is an augmentation of the inhibitory effect on the succeeding test plant. Further evidence for inhibition rather than exhaustion of nutrients was obtained in experiments in which reduction in nodule number was obtained by watering test plants with staled medium obtained from another culture vessel. Attempts to increase the inhibitory activity of staled media by direct concentration were inconclusive.

Addition of chemical adsorbents such as activated charcoal markedly stimulated both nodule and root development. Below about 5 per cent of charcoal in the medium, the stimulation was proportional to the quantity present and independent of the effectiveness of the strain of nodule bacteria used as inoculum. Of the other adsorbents used, Bentonite, Fullers earth and to a lesser degree, asbestos were stimulatory, kaolin, silica gel and celite had no activity, and zeocarb, deacidite and magnesium carbonate were harmful to plant growth. Increased nodulation with the active adsorbents occurred from pH 4·0—8·0 and in each case and in the controls maximum nodulation occurred at pH 5·5. Experiments are being continued on these lines with the object of obtaining critical chemical evidence for the presence of an inhibitory substance.

In the course of these experiments it was observed that with bentonite in the medium an intense blue-green colour developed in the immediate vicinity of the root. This colour was obtained with red and white clover but no colour was observed with oats, ryegrass or radish. Lucerne gives a faint brown colour, vetch an orange brown and flax a citron yellow. The blue-green stained bentonite removed from the clover cultures fades to a purple-brown on drying unless it is first acidified with 10 per cent mineral acid. Addition of alkali discharges the colour which may, however, be restored by reacidifying. The colour is not removed by moderate leaching with acid salt solution or organic solvents but is destroyed by heating

to 100°C. These colour reactions are being further investigated although the root exudation responsible may not be concerned with nodule inhibition. Colour reactions are known between clay minerals and certain organic compounds, notably Vitamin A and carotenoids and some aromatic amino compounds.

Work has also been in progress during the year on the inheritance of the effectivity response in red clover and further confirmatory experiments have been carried out on nodule excision.

BOTANY DEPARTMENT

By D. J. Watson

Dr. E. C. Humphries, Miss J. M. Thurston, Dr. K. Warington and Dr. D. J. Watson attended the VIIth International Botanical Congress held at Stockholm in July. Dr. Humphries read a paper on nutrient uptake by excised roots, and Dr. Watson on some effects of virus infection on the carbohydrates of sugar beet.

Dr. Humphries was awarded the degree of D.Sc. of the University of London.

Work done during the year followed on the lines of that described in the 1949 report, and no new investigations were started. The development of growth-analysis studies intended to throw light on the physiology of variation in crop-yield has been held up by lack of facilities for growing plants in controlled environments. Without them it is not possible to disentangle the effects of internal factors of the plant and external conditions, nor to obtain precise information on the effects of environmental factors and their interactions. These matters, which are fundamental to an understanding of the growth of crop plants, are still controversial, and until they are cleared up, it is difficult to interpret the results of previous work at Rothamsted and other places. Much time has been spent on the planning of suitable controlled-environment rooms, and it is hoped that before long it may be possible to proceed with their construction.

The results of wartime work on the storage of potatoes in clamps, previously available only in part in a report to the Agricultural Research Council, have now been published (35, 36).

Micronutrients (K. Warington)

Experiments have been carried out in solution culture to study the interaction between molybdenum and manganese in plant nutrition. Other workers have claimed that in some conditions the addition of molybdenum may increase the sensitivity of plants to manganese deficiency, and that molybdenum in high concentration may offset the toxic effect of excess manganese or other heavy metals. The two elements were supplied in varying combinations of rates ranging from those known to be adequate for normal growth (0·1 p.p.m. Mo and 1·0 p.p.m. Mn) to those liable to be toxic (20 p.p.m. Mo and 25 or more p.p.m. Mn). Oats, flax and soybean were selected as test crops. Observations made during growth showed that the tolerance of high Mn supply varied considerably between flax and soybean on the one hand, and oats on the other. Oats were unharmed by concentrations of over 100 p.p.m. Mn, whereas growth of flax and soybean was seriously affected by 10 or 20 p.p.m. All the crops responded similarly to Mo, and were unexpectedly tolerant to the high rates of supply; increase in the concentration to 20 p.p.m. did not reduce the dry weight yield. Chemical analyses of the plant material are still in progress. So far, no evidence has been found to support the claim that increased molybdenum supply mitigates the toxic effect of

excess manganese, but this effect may occur only in restricted conditions different from those of the present experiment, and further work will be done to test this.

Nutrient Uptake by Excised Root Systems (E. C. Humphries).

Investigations of the effect of the nutrient content of excised roots on the rate of ion uptake from a nutrient solution was continued. An account of the methods used, and the results of some preliminary experiments has been published (31). Statistical examination of the considerable body of data collected has occupied much time and is not yet complete. It has been established that the rates of uptake of nitrate, phosphate and potassium all depend on the total soluble carbohydrate content of the root, but apparently not specifically on sucrose or reducing-sugar content. The rate of uptake of each of these nutrients decreases with increases in the concentration of the same nutrient in the root ; the question as to whether it is also affected by the concentration of the other nutrients is being examined, but a definite answer cannot yet be given.

Experiments have been made to study (a) the effect of sucrose added to the nutrient solution on the rate of ion uptake ; (b) the relative rates of absorption and assimilation of nitrate and ammonia by nitrogen-deficient roots, and (c) the effect of molybdenum and manganese deficiencies on the rates of absorption and assimilation of nitrate and ammonia. Chemical analysis of the material from these experiments is still in progress.

In connection with these nutrition studies attention has been given to the problem of rapid estimation of the chief cations normally present in plant ash. For this purpose a flame-photometer has been constructed. A number of difficulties in its use have been encountered, the principal one being the mutual excitation of potassium by sodium and *vice-versa*, but satisfactory methods for estimating potassium, sodium and calcium are now in sight. The sensitivity and accuracy of the instrument have been increased by the use of interference filters and photomultipliers.

Uptake of Mineral Nutrients by Leaves (G. N. Thorne).

Work on the uptake of mineral nutrients from solutions sprayed on leaves, started late in 1949, has been continued. It is not yet possible to report on the results fully, as many chemical analyses on the plants grown in the 1950 experiments remain to be done. Uptake of nitrogen, phosphorus and potassium through the leaves in appreciable amounts compared with normal uptake through the roots has been confirmed with cabbage, sugar beet, french beans and barley. No difference was detected between the amounts of nitrogen taken up, when it was supplied as ammonium or nitrate ions, in solutions of equal concentration.

The effect of spraying leaves with nutrient solutions on growth and yield has been studied in a pot experiment on sugar beet with varied nutrient supply to the soil. Plants sprayed with nutrient solution showed a significant increase in leaf area after 4 weeks, and in root weight after 7 weeks, compared with control plants sprayed with water. The final yield was also substantially increased ;

in the extreme case, with low nutrient supply to the soil, the final dry weight per plant was increased by 75 per cent by spraying with the more concentrated of the two nutrient solutions tested. The effect on yield increased with increase in the concentration of the spray solution, and decreased with increase in nutrient supply to the soil. Nutrient uptake from the spray solution was greater at the higher level of nutrient supply to the soil, presumably because the leaves were larger and held a greater volume of spray. Daily spraying produced greater increase of yield than spraying once or twice weekly.

The dry weight of brussels sprouts plants was also increased by spraying, but other species showed no response. Tomato plants showing symptoms of nitrogen and potassium deficiency were apparently unaffected by spraying, either in yield or in the severity of the deficiency symptoms. It is not yet known whether they absorbed any nutrients from the spray solution. Similarly, the growth of french beans was not improved by the nutrient spray.

Water Relations of Germination (P. C. Owen).

The study of the dependence of germination and water uptake of wheat seeds on water potential, in collaboration with the Physics department (1949 Report, p. 49) has been continued. Data on the progress of water uptake with time have been obtained for both living and dead seeds over a range of water potential from zero (saturated atmosphere) to —250 metres of water. In the initial phase, the curves of water uptake by seeds, held in an atmosphere with constant water potential, plotted against time have an exponential form approaching an asymptotic water content (y'), and are well fitted by the equation :

$$y' - y = (y' - y^\circ)e^{-at}$$

where y° is the initial water content, and y the water content at time t. The water content of dead seeds comes to equilibrium at the asymptote, but with the onset of germination in living seeds there is a second phase of water uptake, also exponential in form, fitted by the equation :

$$y - y' = (y' - y^\circ)e^{bt}$$

Work is being continued to confirm and interpret these relationships. Curves of water uptake by seeds held in atmospheres with different water potentials give values of a in the first equation that increase, apparently linearly, with decrease in potential over the range from zero to —250 metres. It has been shown that change in the width of the air gap between the seed and the salt solution over which it is held has no effect on the rate of water uptake, indicating that the resistance to water movement in the gas phase is very small compared with that within the seed.

The similarity of the first phases of water uptake in living and dead seeds suggests that this phase is a physical rather than a physiological process. The second phase of uptake in living seeds is presumably associated with growth and water absorption by the embryo.

Biology of Wild Oats (J. M. Thurston).

The responses of *Avena fatua, A. ludoviciana,* winter oats and wheat to added nitrogen were compared in a pot experiment, to find out whether there are differences in the efficiency of utilization of the available nitrogen supply that may account for the ability of wild oats to compete successfully with cereal crops. No marked differential response in final dry weight was found ; analysis of the data for earlier growth stages is not yet completed. Seeds from this experiment are being used to test whether the nitrogen nutrition of the plant affects the dormancy and viability of the seeds it produces.

Field observations (1949 Report, p. 50) have suggested either that viable wild-oats seed may survive in farmyard manure, or that farmyard manure may break the dormancy of seed present in the soil. Some samples of dung have been tested for the presence of viable wild-oats seed, but none have been found. Evidence in support of the second possibility, that farmyard manure may shorten the period of dormancy, has been obtained. In a glasshouse experiment, 50 per cent more seeds of both species germinated in the first season when sown in farmyard manure than when sown in soil. To confirm this result for field conditions, the effect of farmyard manure applications on the number of seeds germinating is being tested in a field known to be heavily infested with *A. ludoviciana.*

A field experiment has been started to give information on the seasonal germination and on the period of survival of *A. fatua* and *A. ludoviciana* seeds in the soil and on the effect of depth of sowing and of varying intensity of cultivation. A uniform infestation has been established by sowing equal numbers of seeds per plot on a site free from natural infestation. The time course of germination will be followed over a period of years.

A start has been made in collecting information on the distribution of *A. fatua* and *A. ludoviciana* in England. Of thirty-two samples of seed, mostly from the eastern counties, all but one contained *A. fatua,* the grey-husked var. *pilosa* and the brown-husked var. *pilosissima* being commoner than the yellow-husked var. *glabrata.* A small quantity of *A. ludoviciana* was present in two samples in addition to *A. fatua.* Only one sample, from Oxfordshire, consisted entirely of *A. ludoviciana.* These results suggest that *A. fatua* is much commoner in eastern England than *A. ludoviciana,* but it is possible that in some cases seed of the latter may have been shed before the samples were collected. In co-operation with the National Agricultural Advisory Service it is hoped to arrange for systematic collection of samples over a wide area in 1951.

Physiological Effects of Virus Infection (J. H. Wilson).

The pot-culture experiment carried out in 1949 (1949 Report, p. 51) showed that infection with leaf-roll virus greatly reduced the dry matter increments of potato plants at all stages of growth. This was partly due to a reduction in leaf area, but the net assimilation rate was also decreased, indicating that the rate of photosynthesis of infected leaves is less than that of healthy leaves. An experiment was made to find out whether the effect of infection on photosynthesis is due directly to the presence of the virus and

occurs in all leaves of infected plants, or whether it is a secondary effect associated with the rolling of the leaves. Three groups of infected plants were set up (a) with the unrolled upper leaves removed ; (b) with the rolled lower leaves removed ; (c) intact plants, and there were three corresponding groups of healthy plants with the same leaves removed or retained as in the infected groups. The net assimilation rate of infected plants was reduced, compared with the healthy controls, only in the two groups which retained the rolled leaves. The net assimilation rate of infected plants carrying only unrolled leaves differed little from that of the corresponding healthy plants. It follows that assimilation by infected leaves is not reduced until the rolling of the leaves develops.

In a further study of the influence of nitrogen supply on the expression of leaf-roll symptoms, Up-to-date, a variety tolerant to leaf-roll, was compared with the intolerant variety, Craig's Defiance, previously used. With low nitrogen supply, both varieties showed very severe symptoms. Addition of nitrogen appreciably reduced the severity of symptoms in Craig's Defiance, but in Up-to-date symptoms were completely suppressed almost until the time of flowering and were then of only mild intensity.

The 1949 experiments indicated that the transport of dry matter from infected tubers to the developing shoots is slower and less complete than from healthy tubers. To test this, setts of three different sizes cut from healthy and infected tubers were planted in gravel culture, and estimates of the loss of dry matter from the setts during the early stages of shoot growth were obtained by harvesting replicates at intervals after shoot emergence. From a preliminary examination of the results it appears that leaf-roll infection retarded transport from the tubers of intolerant varieties such as Craig's Defiance, but had little effect in tolerant varieties such as Up-to-date.

Field Observations

Records of the weeds present on the Broadbalk and Hoosfield plots, and of the flora of the Park Grass plots, were made as in previous years.

STATISTICS DEPARTMENT

By F. Yates

During 1950 the work of the department was continued along the lines which have been outlined in previous reports. Work on the design and interpretation of experiments, particularly for the National Agricultural Advisory Service, has continued to grow.

On the survey side, work on surveys of the operational research type has again been at a high level. The Survey of Marginal Land was completed, and the data provided proved of assistance to the Committee set up by the Ministry of Agriculture to advise the Government on future policy with regard to such land. It will be recalled that the object of the survey was to investigate how far marginal land of the type not included in the Hill Farming Act and not producing cash crops such as dairy products was likely to repay a scheme of rehabilitation. Government assistance has since been provided for such land on the lines recommended by the Committee. The third and final year's field work of the Survey of Maincrop Potatoes has been completed, and the results are now being analyzed. A further Survey of Fertilizer Practice was carried out in nine districts scattered over the country. Two further districts are at the moment awaiting survey. The object of this survey, which will be repeated in 1951 and probably in 1952, is to see what changes in fertilizer practice are taking place as a result of the considerable alterations in price consequent on the changes in subsidies. The preliminary work on the Survey of Opencast Coal is completed and detailed work is about to commence. Local surveys on garden chafer beetles and brassica crops were also carried out in conjunction with the National Agricultural Advisory Service.

The first full year's working of the Hollerith equipment has proved its value. Modifications, basically designed by members of the department, increasing the scope and versatility of the tabulator, have now been installed.

During the last few years the need for additional accommodation has become increasingly pressing. At the beginning of 1950 it was decided that the best course would be to construct a new building to house the entire department, leaving Rivers Lodge free for other purposes. Detailed plans for this building have now been completed.

Design and Analysis of Experiments

The design and analysis of field and laboratory experiments for Rothamsted and other research stations has continued on the usual lines. Co-operation with the National Agricultural Advisory Service in the field of experimental design and analysis has again made very good progress. We are continuing to be consulted by all provinces, and Dr. Boyd or some other member of the department usually attends meetings of the Provincial Experiments Committees in most provinces.

The Crop Experiments Sub-Committee and the Animal Experiments Sub-Committee of the Ministry of Agriculture's Experimental

Husbandry Committee have been very active during the year considering proposals and making plans for experiments at the Experimental Husbandry Farms. Dr. Yates is a member of both these Committees and recently Mr. Rees has been assigned the task of assisting in the statistical work on the animal side. He prepared a note summarizing the results of experiments on the feeding of sugar beet and fodder beet to pigs (49). It is intended that an expanded version of this note shall be published. This headquarters organization is now playing an increased part in the planning of co-operative experiments carried out by the National Agricultural Advisory Service. Dr. Yates has also assisted in some of the preliminary work concerned with the planning of experiments for the Experimental Horticulture Farms. In this he was assisted by Mr. Nelder, statistician to the Vegetable Research Station who, as mentioned in the previous report, has been housed in the department during the past year pending the completion of buildings at Wellesbourne.

A good deal of attention has been paid to the problem of estimating the yields of the herbage plots on the Ley-Arable experiment at Rothamsted by means of grazing sheep, and by cutting samples of grass. The actual field work in connection with the cutting of grass samples has been undertaken by members of the department. The results as far as the sheep are concerned have been disappointing, but it is hoped that changes in technique may effect an improvement.

Various problems in the theory of the design of experiments have been investigated in the course of the year. Dr. Grundy has prepared a paper on a general technique for the analysis of experiments with incorrectly treated plots (39). Previous to this paper each case in which plots were incorrectly treated, e.g. by transposing two treatments, had to be analyzed by least squares methods, except for a limited range of problems in randomized blocks. The present research provides a method which is widely applicable and can be carried out without any complicated algebra. Mr. Healy wrote a paper on the design of probit assays (40). This dealt with the commonly used 2×3 point design and gave graphs from which the number of test objects needed to attain a desired degree of accuracy could be roughly assessed in advance. He has also described the methods used in a special case of analysis of non-orthogonal experimental data which should be of considerable value as an illustration of the way in which the best use may be made of such data (41). He collaborated with Mr. Leach of the Veterinary Laboratory, Weybridge, in clearing up some confusion which had arisen in correspondence in *Nature* on the statistical analysis of the results of successive tests on the same organism (45).

Mr. Patterson has continued his work on long-term and cyclical experiments. He also collaborated with Mr. Dyke in the development of a method of analyzing non-orthogonal factorial arrangements in which the data are in the form of proportions. In such cases it is necessary to scale the data, since the postulate of additive effects of the various factors, which forms the basis of the ordinary analysis of variance procedure, cannot operate over the limited

range, from 0 to 1, of the proportions. The scaling transformation proposed for the proportion $p(=1-q)$ is

$$z = \tfrac{1}{2} \log_e p/q$$

A paper is in the course of preparation.

Sampling Methods

A considerable amount of advice on the design of sample surveys of various kinds has been given to people working in agriculture and other fields, both here and abroad. Dr. Yates attended the 4th Session of the United Nations Sub-Commission on Statistical Sampling where he contributed a paper to a discussion on operational research (50).

Survey of Fertilizer Practice

In view of changes which might be expected in fertilizer practice arising from the reduction and modification of subsidies this survey was carried out in nine districts scattered over the country during the year. A further two districts are awaiting survey. It is proposed that comparable districts should be surveyed during the next year or two so as to enable trends to be examined.

The primary objects of the survey are to determine the amounts of fertilizer used on the different crops in different districts of the country. In addition, information has been obtained on methods of fertilizer distribution and times of application, and wherever possible soil analyses have been carried out for a sub-sample of the surveyed fields. Supplementary information has been sought on the availability of fertilizers and on the opinions of farmers regarding the use of nitrogen for cereals and for grassland.

The field work has been carried out, as in previous years, by the National Agricultural Advisory Service through the provincial Advisory Chemists. As a Hollerith installation is now available in the department and as the number of districts surveyed during the year was larger than usual, the returns have been handled on punched cards. This has made it practicable to examine the data in numerous ways and, in particular, various systems of weighting are being examined for bias and the sampling errors of estimates are being investigated.

A brief summary of this year's results is given in a separate article in this report.

During the year reports have been prepared on earlier surveys in two districts (48a, 48b).

Survey of Maincrop Potatoes

The Survey of Maincrop Potatoes which was begun in 1948, has now completed its third and final year, and the results are at present being analyzed. It will be recalled that the survey had been carried out in co-operation with officers of the National Agricultural Advisory Service. The survey is intended to furnish comprehensive and precise information on the agricultural practices followed in growing maincrop potatoes. It is also designed to test the possibility of estimating the yield of the crop by digging and weighing

short lengths of row shortly before harvest, and also to test the possibility of forecasting the yield of the crop by digging up similar lengths of row at an earlier date. The interim report on the first two years' results is being published in the National Agricultural Advisory Service Quarterly Review (38). It is hoped that a further report on the whole survey will be issued during 1951.

Although the average yields were decidedly lower in 1949 the comparison between the yields obtained from the survey with those of the corresponding Ministry estimates gave very similar results in 1949 to those obtained in 1948. These comparisons are shown in the following table.

TABLE 1. *Comparison of net sample yields with estimates of the Ministry of Agriculture (tons/acre)*

	1948	1949
Ministry of Agriculture estimates (excluding first earlies—sampled counties only)	8·1	7·2
Deduction for seed and chats (estimated from the survey results)	0·3	0·4
	7·8	6·8
Net yield of ware (1¼ in.) from samples	9·5	8·5
Difference	1·7	1·7

The results for 1948 differ from those already given for that year in the 1949 Rothamsted Report mainly because a deduction has now been made from the Ministry's estimates for seed and chats. It has now been verified that the Ministry's estimates are intended to include seed and chats. On the other hand, it should be borne in mind that the Ministry's estimates include second earlies, whereas the survey results refer to maincrop potatoes only. Also the sample yields do not take into account losses in the clamp—nominally this is also true of the Ministry estimates, but some unconscious allowance may be made for such losses.

It will be seen that the discrepancy between the sample yields and the Ministry's estimates is identical in both years. The returns for the separate districts indicate clearly that the discrepancy arises mainly through under-estimation of the yields of the high-yielding counties. This is shown in the attached figure.

In both years the estimates obtained from the samples were compared with the farmers' weighed yields in cases where these were available, mainly cases in which the potatoes were sold directly off the field. This comparison is shown in the following table which also shows the allowances which had to be made for the amount of ware left in the ground, and for over-statement of the acreages actually grown. These allowances were determined by supplementary sampling. In both years the agreement between the correct sample yields and the farmers' weighed yields is very satisfactory. The large quantity of potatoes left in the ground, about three-quarters of a ton of ware potatoes per acre, is also noteworthy.

TABLE 2.* *Comparison of farmers' weighed yields and sample yields (tons/acre)*

		1948		1949
Number of fields		136		72
Mean yield (gross) of ware from samples (1¼ in. riddle)		11·3		8·9
Less : ware left in ground ..	0·8		0·7	
deduction for acreage correction	0·4		0·4	
deduction for change of riddle to 1½ in.	0·3		—	
Total deduction		1·5		1·1
Mean yield (net) from sample ..		9·8		7·8
Mean of farmers' weighed yields ..		9·5		7·8
Mean excess of sample over weighed yields		+0·3		0·0

* Occasional small discrepancies between the present tables and those issued in earlier reports are due to rescrutiny of the data or minor changes in methods of calculating.

Some preliminary comments on the agricultural practices in the growing of potatoes will be found in the report referred to above. Fuller comment must await the complete analysis of the three years' results.

OTHER SURVEYS

As mentioned in the introduction the Survey of Marginal Land in England and Wales was completed in the early part of 1950. Sanction has now been obtained to prepare a report for publication.

A survey was undertaken jointly with the National Agricultural Advisory Service South-Western Province of an area of downland in Dorset which was heavily infested with the garden chafer, *Phyllopertha horticola*. The survey was designed to assess what bearing, if any, the management of the grassland had on the incidence of chafer attack. The survey showed that although permanent grass fields in the area were frequently infested leys grown on similar soils with similar management and manurial treatment were free from infestation. It was also found that permanent grass fields which were shut up for hay were more susceptible to attack than those which were used solely for grazing. A report has been sent to the provincial officers.

Advice was given on the design of a survey of brassica crops which are grown for stockfeeding in Wales. Information is being collected on the methods of cultivation, the yields and the utilization of the crops.

A survey is being made in conjunction with the Ministry of Agriculture of restored opencast coal sites ; the two main objects of the survey are to compare the condition of the land after restoration with the original condition before it was disturbed, and to make recommendations for improving technique of restoration for the future. The first stage of the survey, that of the enumeration of the

sites and the collection of preliminary material, has just been completed. During 1951 it is hoped to survey a sample of sites in more detail.

Colonial Work

Mr. Hodnett was appointed on 1st August, 1950, to the post of Colonial Statistician. He is to work specifically on colonial problems. He has already dealt with a number of enquiries from colonial territories, including methods of calculating the sampling errors in a survey of population in Basutoland. He is now engaged in summarizing the results of previous colonial experimental work on sugar cane.

Mr. Church has also assisted in colonial work, particularly before the arrival of Mr. Hodnett. He gave advice on a census of population carried out by the Department of Economics and Trade, Sudan Government. He also paid a short visit to the West African Cacao Research Institute and other agricultural institutes in West Africa.

Other Work

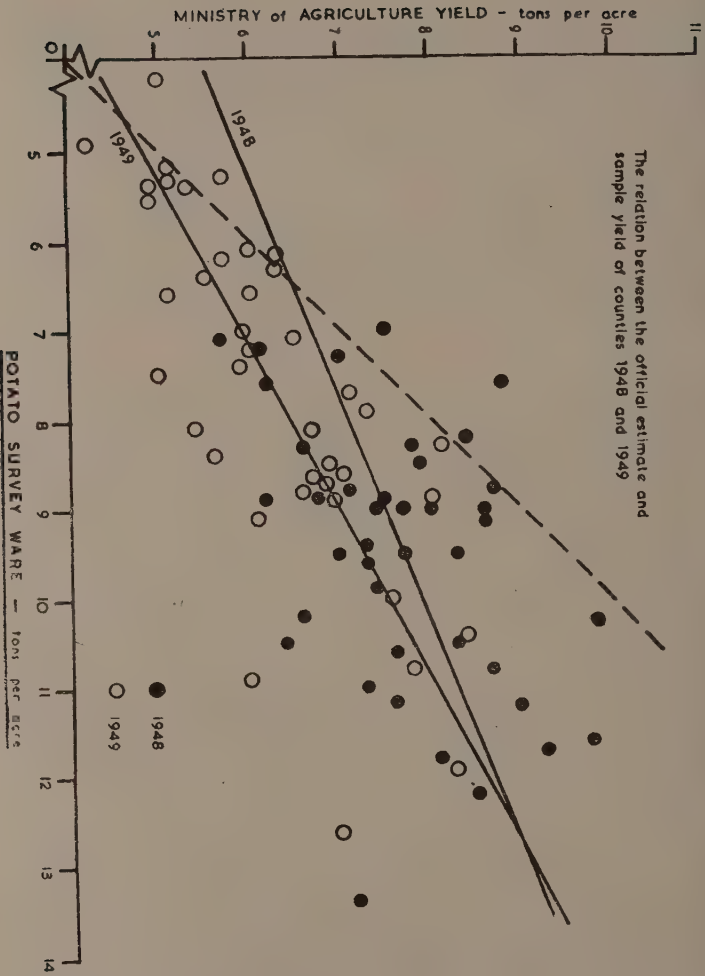
Mr. Dyke has continued to act as statistical adviser to the Advisory Entomologists. He has also been selected as representative for the Ministry of Agriculture on a Joint Committee with the Association of British Insecticide Manufacturers.

Mr. Healy has continued his assistance in the analysis of a series of anthropometric observations for the Department of Anatomy, Birmingham University. Some interesting new methods have been evolved in the course of this work and it is hoped that a paper on the subject will be prepared in 1951. Dr. Yates contributed to a symposium on the study of growth and form held by the Royal Society (42),

The department was requested by the Ministry of Agriculture to give a short course of instruction on statistical methods to the Advisory Bacteriologists of the National Agricultural Advisory Service. This course was held in February, 1950, at Rothamsted, and was attended by 10 officers. Various members of the department gave lectures and assisted in instruction, and Mr. C. P. Cox of the National Institute for Research in Dairying also lectured and gave other assistance. The course extended over a fortnight and was adjudged by the participants to be a great success.

During his trip to the United States Dr. Yates took the opportunity of visiting Canadian and American research institutes. In the course of this visit he had the honour of representing Rothamsted at the 75th Anniversary of the Connecticut Agricultural Experiment Station, the oldest agricultural experiment station in the United States.

Dr. Yates prepared a chapter for a symposium on world production of food (43), and a paper for the Journal of the American Statistical Society on the influence of R. A. Fisher's *Statistical Methods for Research Workers* which was published twenty-five years ago (44). Two reviews were also prepared by Dr. Yates (46, 47).



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Hollerith Equipment

The tabulator has now been in use for a year and a half and has fully proved its value. As mentioned in the introduction certain modifications increasing its scope and flexibility were installed in October, 1950. The idea of these modifications and the principles of their design originated with members of the department. Their main features are as follows :

1. Control of the distribution between counters of numbers read from the cards by means of information punched in more than one control column. Amongst other things this enables interactions of replicated factorial experiments to be calculated directly from the codes for the separate factors.
2. Increased control of the distribution of numbers between counters from the codes punched on a single control column. This makes possible the summation of products from single figure multiplication without sorting, and consequently replaces progressive digiting, a great advantage when a series of short runs of multiplications are required. A particular application of special value in survey analysis is in weighting by single figure weights, percentages, etc.
3. The alterations required for 1 and 2 also enable digital counting to be carried out without sorting.

The speed of the machine has also been increased from 80 to 150/100 cards per minute.

The classes of work that have been undertaken on the machine so far have been :

(a) the analysis of surveys ;
(b) the analysis of replicated experiments ;
(c) multivariate analysis of various classes of biological material ;
(d) the solution of mathematical distribution problems, etc., arising in biological research.

The installation of the modifications referred to above has greatly increased the scope and flexibility of the installation for the types of work with which we are mainly concerned. This is shown by the loading of the tabulator. Detailed records of the loading have been kept since the beginning of 1950 and are as follows :

	Days of work (average maximum 24 days)
January	12
February	12
March	13½
April	15
May	14½
June	12
July	7½
August	15
September	8½
October	21½
November	22½

The tabulator is now fully loaded, indeed for our class of work during the last two months it has been somewhat overloaded. Full loading is expected to continue.

From the experience of the last one and half years it is clear that the installation of Hollerith equipment under the direct control of scientific workers has been of considerable value. It has resulted in a much more enterprising and flexible approach to punched-card-work than was the case when all tabulations had to be carried out at a separate bureau. Moreover the modifications which have been installed would certainly not have been thought out had we not ourselves been in direct contact with the machine. These modifications are likely to have wider applications outside our own department ; an Australian worker who recently spent two months in the department has already approached the British Tabulating Machine Company with a view to arranging a similar installation in his department in Australia.

The installation of the equipment is also leading to the development of statistical methodology in new fields which had previously been neglected owing to lack of adequate computational facilities. For example, for the first time we have been able to tackle seriously multivariate analysis work. This type of problem is continually recurrent in biological and other research, but owing to lack of computational facilities in the hands of statistical research workers who are best acquainted with the problems involved and the theory already developed, the subject has hitherto made very slow progress.

PLANT PATHOLOGY DEPARTMENT

By F. C. Bawden

Two new appointments were made in August, when Mr. J. M. Hirst and Dr. F. T. Last began work on the epidemiology of potato blight and cereal mildews.

Six members of the department attended the Seventh International Botanical Congress at Stockholm in July, and papers were read by Mr. F. C. Bawden, Dr. M. D. Glynne, Dr. P. H. Gregory, Dr. R. Hull and Dr. M. A. Watson ; Mr. Bawden was Vice-President of the Phytopathology Section.

Dr. Gregory attended the Fifth International Congress of Microbiology at Rio de Janeiro in August and read a paper entitled *The efficiency of spore traps used in the study of aerobiology* ; Mr. Bawden was President (*in absentia*) of Section VII (Plant Pathogenic Micro-Organisms).

In March and April Mr. Bawden gave a course of lectures on Plant Viruses and Virus Diseases at Yale University ; he also attended a conference on viruses at the California Institute of Technology, Pasadena, and visited other Universities and Research Stations in the United States of America and in Canada.

Dr. B. Kassanis was awarded the degree of D.Sc., and Mr. R. H. E. Bradley the degree of Ph.D. of London University.

Viruses and Virus Diseases

Laboratory and glasshouse work

In previous reports the anomalous behaviour of the Rothamsted tobacco necrosis virus has been mentioned, particularly the variations in infectivity of different preparations and the occurrence in sap from infected plants of specific nucleoproteins with two different particle sizes. Further work on the purification and properties of this virus has produced preparations with greater infectivity than that of those obtained previously. The relationship between the particles of two different sizes still remains obscure, but evidence accumulates that not all the specific nucleoprotein is infective. Some particles seem to become infective only after being liberated into the sap, infectivity apparently being conferred by some mechanism which is activated when leaf cells are injured and which is destroyed by freezing undamaged leaves. Exposure to citrate destroys the infectivity of this virus without denaturing the nucleoprotein or affecting serological activity. The inactivation by citrate depends greatly on other factors, which may partially explain the variations in infectivity found with different preparations of this virus (76, 77).

Much time was spent testing various spraying techniques in attempts to produce uniform droplets suitable for counting virus particles by electron microscopy, but so far great difficulty has been encountered in getting consistent results. Isolated intracellular inclusions from plants infected with several different viruses were examined in the electron microscope. Those from plants infected with tobacco mosaic, tomato aucuba mosaic, cabbage blackring and henbane mosaic viruses appeared to be composed largely of

bundles of rod-shaped particles similar to those earlier demonstrated in mounts of clarified infective sap (62). Rod-shaped particles were also detected in inclusion bodies formed by tobacco etch virus, but these were over-lain by other material, suggesting that the bodies may have a membrane. The inclusions formed by cauliflower mosaic virus were so stable that they could not be broken into fragments small enough for electron microscopy, and, as with examinations of infective sap, no particles could be identified as likely to be virus particles.

Previous attempts to identify any specific particles in sap from sugar beet with yellows have failed, but electron micrographs of the precipitate produced by mixing infective sap with virus-antiserum showed clusters of rods adhering to larger masses of indeterminate shape. The rods appeared to be destroyed when the sap was frozen, though the sap was still serologically active. Similar rods were also seen occasionally in sap from infected beet without precipitation with antiserum. Their relationship with the virus is uncertain and they would seem to be too few to form more than a minor component of the antigens specific to yellows-infected plants ; also, the somatic type of precipitin reaction suggests that most of the antigen particles are not rod-shaped.

At the request of workers in the Gold Coast and in East Africa, attempts were made to identify the particles of cacao swollen shoot and groundnut rosette viruses. Electron micrographs were made of extracts from various organs of infected plants but these showed nothing that was not also present in comparable extracts from healthy plants. Groundnut rosette virus, which hitherto had been transmitted only by grafting and aphids, was transmitted mechanically, though only with difficulty; about 10 per cent of healthy seedlings inoculated with sap from diseased plants became infected if they were placed in darkness for a few days immediately before inoculation and an abrasive was incorporated in the inoculum. Similar methods failed to transmit cacao swollen shoot virus ; the Rothamsted tobacco necrosis virus, however was readily transmitted by inoculation to and from leaves of cacao.

Previous studies on the effect of dilution on the numbers of local lesions produced by plant viruses have shown that results are incompatible with the generally held idea that infection occurs because of chance encounters between single virus particles and uniformly susceptible sites. To gain further information on this problem, experiments were made with a virus that attacks clover-nodule bacteria. These showed that single particles can infect bacteria, but that not every particle succeeds in doing so, and the chance of one doing so depends on the conditions in the bacterial culture. By analogy, it seems that infection of crop plants may also be produced by the action of single virus particles, but that susceptible sites in the inoculated leaves are not uniform, so that the chances of a virus particle becoming established differs at different sites (73).

Work has started on the inactivation of plant viruses by irradiation with ultra-violet light. Workers studying some bacterial viruses have found that irradiated particles that are non-infective when acting singly may cause infection when two or more enter the same bacterial cell. No evidence has been obtained that plant

viruses behave in this manner, but evidence is accumulating that virus inactivated by irradiation specifically interferes with infection by active virus.

Host-plant physiology

The fact that carbohydrates accumulate in leaves of sugar beet with yellows has long been known and generally attributed to failure of normal translocation because of phloem necrosis. This is not the correct interpretation, however, for during a period of darkness yellowed and healthy leaves lost equal quantities of carbohydrate (37). Spraying infected sugar beet leaves daily with 2 per cent and 10 per cent sucrose solutions increased the severity of the symptoms in conditions of low light intensity when they normally are masked. Spraying produced no symptoms in uninfected plants, though it increased their carbohydrate content, and it was concluded that the external symptoms of yellows require a high sugar content, but they are not directly caused by it.

Reducing the light intensity under which plants are raised has previously been found to increase their susceptibility to infection by mechanically transmitted viruses. Experiments with henbane mosaic and sugar beet yellows suggest that there is no comparable increase in susceptibility when viruses are introduced by aphid vectors. Differences in susceptibility comparable with those produced by varying illumination were also produced by varying the amount of water supplied to plants before they were inoculated, those receiving abundant water giving many more local lesions than those kept drier. These differences are possibly correlated with the thinner cuticle and disorganized palisade cells that characterize plants grown in a saturated soil. The differences between plants receiving different amounts of water were reduced, but not abolished, by shading or by incorporating an abrasive in the inoculum. Differessential watering appeared to have no consistent effect on the extent to which tobacco mosaic virus multiplied in systemically infected plants.

The freeing of Majestic potato tubers from leaf roll by heating for 20 or more days at 37·5°C. was confirmed, and the effect shown to be permanent. Plants in the third generation as progeny from heated tubers were still without symptoms, and there seems little doubt that such treatment destroys the leaf roll virus in infected tubers and does not merely produce a temporary masking of symptoms (71).

Transmission by aphids

The readiness with which aphids became infective with potato leaf roll virus was found to depend greatly on the age of the plants on which they are fed. When feeding on potato plants, many more aphids became infective after feeding on emerging sprouts, which were symptomless, than after feeding for similar lengths of time on older plants which showed pronounced symptoms. Similarly, with *Datura tatula*, plants infected for only a fortnight and showing slight symptoms were a better source of virus for aphids than were more severely diseased plants that had been infected for longer periods. It seems likely that the concentration of infective virus reaches its

highest level early in the course of infection and then declines as the leaf symptoms develop. This may help to explain the fact that, in most years, the main spread of leaf roll in crops at Rothamsted occurs early in the season.

Using *D. tatula*, which reacts more quickly than potato, shows more definite symptoms, is more easily infected and is a better source of the virus for aphids than potato, some of the factors influencing the transmission of the leaf roll virus by *Myzus persicae* were studied. The results confirmed that leaf roll virus persists for many days in the aphids and that aphids cannot infect healthy plants immediately they have acquired the virus. Aphids that had fed for two hours on infected plants became infective, but they did not transmit the virus to healthy plants within the next day. The delay period could be passed while feeding on diseased plants, and aphids which had fed on these for several days could infect healthy plants within the first fifteen minutes of feeding on them.

A virus isolated from a sugar beet found naturally infected at Lincoln seems to be similar to one previously described in the United States of America with the name yellow net. It is not related to beet yellows or mosaic. It is aphid-transmitted and persists in the vector for some time; preliminary results suggest that aphids do not become infective until about two days after they first start to feed on infected plants.

Other viruses whose insect transmission was studied were henbane mosaic, cauliflower mosaic and cabbage black ringspot. None of these persists for more than a few hours in the aphid vectors, and the whole process of acquiring the virus and infecting a healthy plant can occur in less than two minutes. Before settling down to feed continuously, aphids were found to make several preliminary probes into leaves, and these first punctures seem to be the important part of the aphids' feeding habits in transmitting these non-persistent viruses. It was shown that aphids could become infective by feeding on detached epidermal strippings of leaves, and it seems that they normally acquire these viruses from, and transmit them to, the epidermis. When infective aphids were disturbed at intervals and prevented from feeding continuously, they caused more infections than when they were left undisturbed. The probability that a puncture of a leaf by an infective aphid would result in an infection reached a maximum in punctures maintained for about half a minute. The mechanism responsible for such speedy transmission is unknown, but it would seem that only virus which is carried somewhere in the mouthparts of the aphids could be concerned. The process does not seem to be wholly mechanical, for there is considerable specificity between non-persistent viruses and the insects that act as vectors; also, when the stylets of aphids were smeared with infective sap, the aphids did not infect healthy plants on which they subsequently fed.

In attempts to gain further information on the feeding behaviour of aphids, experiments were made with *M. persicae* colonizing turnip and sugar beet plants raised in nutrient solution containing radioactive phosphorus (P^{32}). The results suggest that the method will not help to elucidate the transmission of the non-persistent viruses but may help with the persistent viruses, the vectors of which need

to feed for long periods to become highly infective. When aphids were fed on plants containing the optimum concentration of the tracer, they showed their first detectable radio-activity after 15 minutes. Autoradiographs made of various organs, dissected from aphids that had fed on such plants for different periods, showed slight activity in the stomach after about 10 minutes' feeding; after 1 to 2 days, activity was detectable in all organs except the nervous tissue, but was most concentrated in the stomach of the adult and in the developing ova and nymphs. The activity increased during periods of 24 hours' feeding in a manner suggesting that aphids feed at the same rate during the hours of daylight and darkness.

This suggestion was confirmed by studies on excretion, for aphids excrete honeydew only while feeding, and they excreted at equal rates during periods of light and darkness. The effect of evaporation on excretion was studied in the wind-tunnel and it was found that the rate at which honeydew was deposited was not a reliable indication of feeding rate when external conditions varied. The method of excreting honeydew was studied in 22 aphid species, and was found to be similar in all those that infect aerial parts of plants. Methods were modified in gall-inhabiting and root-feeding species, and it seems that the production of wax by many gall-inhabiting species may be correlated with the need to cover the sticky excretion.

Experiments were made on the effects of high temperatures on the survival of aphids in different conditions. When removed from their host plants and kept for an hour at relative humidity of 50 per cent, the thermal death point of five species lay between 38° and 41°C. Many individual aphids alive at the end of the tests, died within the next day. Increasing the relative humidity during the period of heating increased the number of aphids killed. Fewer were killed when the aphids were kept for the previous four hours at high humidities than when they were kept at low humidities. Aphids on plants withstood temperatures higher than those which killed when they were not on plants, presumably because water lost by evaporation could be replenished.

Field Work

Potato virus diseases

Experiments on the effect of roguing potato crops in south-east England were ended and summarized; the results showed that, although the practice sometimes reduces the spread of virus diseases, the effect is too small to be economically worth-while (65).

The experiment to test the effects of varying planting dates and manurial treatments on the spread of leaf roll and rugose mosaic was done for the sixth and last time in 1950. Tuber samples from the 1949 experiment were planted in 1950 and showed that fertilizer differences did not affect spread significantly; leaf roll spread more in the first-planted than in later-planted plots, but rugose mosaic spread equally in all.

Varying the spacing between potato plants also had no effect on the spread of rugose mosaic, although it had with leaf roll; 18 per cent of the plants adjacent to infected plants became infected

at a spacing of 9 in., 8 per cent at 18 in. and 2 per cent at 36 in. Irrigating plots by over-head watering did not affect aphid populations or virus-spread.

The progeny from a small-scale trial in 1949, when potato plants were sprayed at weekly intervals with DDT, Parathion and Pestox III, showed that spread of leaf roll was reduced from 15 per cent in unsprayed plots to 1 per cent, but rugose mosaic was unaffected, averaging 76 per cent in control plots and 77 per cent in the sprayed. Further experiments to test the effects of five of the newer insecticides on aphid populations and virus spread in potato crops were made in 1950.

A technique for marking aphids with a radio-active tracer was developed ; it was hoped to use this to study the distance to which aphids move in potato crops, but there were too few aphids during the summer for it to be applied. Many winged *M. persicae* entered the crops during May and June, but the activity of predators prevented heavy infestations from developing.

Further evidence that most of the spread of potato viruses is occasioned by winged aphids was obtained from experiments in which some plants were surrounded by sticky boards to prevent wingless aphids from colonizing them (66).

Sugar beet virus diseases

As in previous years much work was done in attempts to devise methods whereby beet yellows could be controlled in steckling beds. The most beneficial measure again found was to raise stecklings in districts remote from other crops of beet and mangolds, but considerable benefit was also derived from other treatments such as growing stecklings under cover crops or spraying with systemic insecticides. These control measures were extensively practised in 1950, when a certification scheme for stecklings was introduced. More than half the total stecklings needed for the British seed crop were grown in isolation and the remainder were raised under cover crops or sprayed. Methods were devised for making inspections of crops and courses of instruction arranged for inspectors. Samples of inspected beds and of all crops raised in isolated districts are being obtained for planting at Dunholme, so that the state of the crops in autumn can be compared with that in the next spring.

Producing stecklings in isolation raises problems of storage and transport, and some unexplained anomalies have arisen. A crop of virus-free stecklings grown in Perthshire, for example, gave an excellent stand when out-wintered in the field or lifted and clamped there but plants sent to Suffolk and clamped there in the autumn failed completely, although the roots looked satisfactory when taken from the clamp. Experiments to determine the best sowing date, cultural practices and storage conditions, for stecklings of sugar beet, red beet, and mangolds, therefore, were started in Scotland.

In attempts to find sugar beet that resist or tolerate yellows, further selections were made from plants that showed relatively little yellowing in the field. There was no evidence from glasshouse tests that the progeny of these were more difficult to infect by aphids than the progeny of other lines, but in the field some of them remained greener when infected. The results of yield trials

to see whether the extent of yellowing is correlated with loss of yield, are not yet complete.

In a field trial on the root crop, late singling was found to reduce the incidence of yellows by enough to increase yield by about two tons of roots to the acre. Late singling had little effect on late sown crops, but on those sown in March it reduced yellows because at the time of the first migration of aphids there were more aphids per plant on the unsingled than on the singled crops, and many of the plants infected in the unsingled crops were eliminated at singling.

To test the influence of mangold clamps in initiating outbreaks of yellows, a scheme was arranged in conjunction with a Farmer's Committee at Bury St. Edmunds, for clearing all clamps by the end of March from an area of 70 sq. miles. The population of winged aphids in this area was compared with that in a neighbouring untreated area by trapping methods, but the catches have not yet been analyzed. Counts in 160 beet crops in and around the cleared area showed less yellows in the area than outside it, but it is not yet known whether the differences are significant.

The species and numbers of aphids infesting clamped mangolds, and the times at which they migrated, were studied in the spring ; species other than *Myzus persicae* are being tested to see whether they are vectors. The control of aphids in mangold clamps, by spraying crops before lifting, and by treatments applied to the clamp, was tested by experiments made in the autumn, but the results will not be known until 1951.

A yellowing disease of sugar beet which was first found in an Irish line (Variety 41) and is seed-transmitted has been mentioned in earlier reports. Further work has shown that the cause is not related to beet yellows virus and that the condition can be seed-transmitted in other lines of beet such as Kleinwanzleben E. It does not seem to be transmitted through the pollen, and infected seedlings were obtained from crosses only when the female parent was infected.

Lettuce mosaic

Epidemiological studies on lettuce mosaic were continued for the third year in the Thames Valley. These studies have shown that, in addition to disease outbreaks initiated by seed-borne infection, many occur because crops are sown or transplanted near to those already infected. Although aphid vectors were numerous during the spring of 1950, serious outbreaks of mosaic were avoided by omitting a crop of winter lettuce, and separating early-transplanted and later-drilled crops into large single blocks at a distance from one another. *Macrosiphum euphorbiae* Thomas, which occurs frequently on lettuce, more particularly during winter, was shown to be a vector of the mosaic virus, but its importance in the field is unknown.

Diseases of cruciferous crops

Virus diseases seemed unusually prevalent in brassicae during 1950 and caused extensive losses, particularly in broccoli. Of the two viruses mainly concerned, cauliflower mosaic was much more prevalent than cabbage black ringspot. Both viruses were trans-

mitted by *Myzus persicae* and *Brevicoryne brassicae* ; in glasshouse experiments, both behaved as typical non-persistent viruses and cabbage black ringspot was the easier to transmit to broccoli, cauliflower or cabbage. Cabbage black ringspot was also found to have a wider host range than cauliflower mosaic virus, so that more sources of infection in wild hosts might be expected. The greater prevalence of cauliflower mosaic virus suggests that it has other insect vectors which do not transmit cabbage black ringspot virus. Surveys were made of the aphid infestation and occurrence of infected plants in commercial crops, as a preliminary to starting extensive field investigations on the spread and control of these viruses.

Mycology

Studies were made with the wind tunnel on the deposition of spores on plane surfaces inclined at various angles to the wind, and the results are being used to improve the design of spore traps and help the interpretation of catches in the field. The total catches and the catches on the different surfaces of horizontal microscope slides varied greatly with wind speed. At speeds around 10 metres per second, catches were high and spores were deposited almost equally on upper and lower surfaces. As the wind speed decreased to 3 metres per second, catches also decreased ; below 3 metres per second, few or none were caught on the lower surface, but catches increased on the upper surface because the effects of gravity become pronounced (69). Spore trapping in the open showed that the main deposition of *Erysiphe graminis* occurred between 15th June and 15th July, and was later and smaller than in 1948 and 1949. There was no heavy deposition of *Alternaria* spores in 1950. In a potato crop, sporangia of *Phytophthora infestans* were caught in large numbers after blight had developed.

Observations in collaboration with Mr. S. Waller were continued on the life history and distribution of the fungus associated with the lethal disease of sycamore trees at Wanstead. The fungus, which presents many novel features, has now been found to resemble *Coniosporium corticale*, previously reported as a saprophyte on maple in Canada and the United States of America.

A rotation experiment to compare the effects of different crops in freeing land from infestation by eyespot, caused by *Cercosporella herpotrichoides* Fron., from take-all, caused by *Ophiobolus graminis* Sacc., and from weeds, was begun after harvesting the 1948 wheat crop in which all three were abundant. Some effects of wheat, winter beans, potatoes and fallow in 1949 on the following wheat crop were recorded in May, 1950 ; 37 per cent of the wheat plants following wheat were infected by eyespot, 27 per cent by take-all ; wheat following beans, potatoes and fallow had respectively 20, 20 and 6 per cent plants infected by eyespot, none by take-all. Wheat after fallow was heavily infested by wheat bulb fly *Hylemya coarctata*, 85 per cent of the plants being affected in March, about two-thirds of them dying later (only 4-8 per cent were affected in wheat after crops). The resulting bare patches became colonized by weeds, which at harvest were almost as abundant after fallow as after wheat ; weeds were much less abundant after beans and potatoes

where a good plant was maintained. Barley had slightly less eyespot than wheat, and oats had very little. Take-all occurred on the barley after wheat, but there was none in any other crops. The eelworm causing tulip root, *Ditylenchus dipsaci*, was found on oats and on some weeds in this experiment, the only record of this pest at Rothamsted since the severe attack on Pastures field in 1934.

A field experiment on the effects of spraying with H_2SO_4, varying seed rates and dates of application of nitrogenous fertilizer, on wheat gave few significant effects of treatments because the crop was heavily and unevenly infested by wireworms which killed many plants. There was also a heavy infestation by the root eelworm *Heterodera major* and a moderate one by wheat bulb fly. In this poor crop, spraying with H_2SO_4, though it reduced the proportion of straws severely infected by eyespot at harvest, did not increase yield of grain.

The effect of applying nitrogenous fertilizer at different dates in a pot experiment showed that the per cent straws severely infected at harvest was reduced (from 77 per cent) by applying the fertilizer in autumn or in early spring (to a mean of 15 per cent) but that application in May did not reduce the disease appreciably.

Eyespot is most severe in wet seasons and spores are probably dispersed by rain, but little is known about the importance of rain falling at different times. To gain information on the point an experiment was made in which rain was excluded and pots were watered either overhead or from below. Overhead watering in December and January had the greatest effect in increasing the incidence of eyespot and the number of plants killed by the disease.

The manner in which host-plant nutrition affects the susceptibility of different cereals to eyespot was examined using plants grown in water cultures. Susceptibility was expressed as the proportion of total leaf sheaths per plant that were penetrated by the fungus before the plants tillered, a method that seems to be more precise than any previously employed. When grown in water, susceptibilities of wheat, barley, oats and rye were 96, 83, 75 and 60 per cent respectively, whereas in nutrient solution the values fell to 72, 25, 10 and 3 per cent.

Corticium (*Rhizoctonia*) *solani*, the cause of sharp eyespot in wheat, was found for the first time causing a severe disease in oats. Some evidence was obtained that the fungus occurs in strains that affect different plants differentially (68).

Further work on the relation between the concentration of spores of *Plasmodiophora brassicae*, the cause of club root, and the number of root-hair infections, showed that logarithms of the two variables are linearly related. Comparisons of results from experiments using new and mature spores suggested that differences were correlated with different proportions of viable spores. Host-plant nutrition was found to affect the proportion of plants that became clubbed when exposed to given spore concentrations. Clubbing was increased by high nutrient levels and early application of nutrients. The proportion of clubbed plants can be used quantitatively for assessing infestation of soil by *P. brassicae*, but only at lower levels of infestation than can counts of root-hair infections and only when the nutrient status is known. New techniques were developed for studying the factors involved in spore germination and the early stages of

infection and it is expected that these will provide more precise information than has been possible previously.

The unusually wet summer led to the earliest and most severe outbreak of potato blight (*Phytopthora infestans*) experienced at Rothamsted for many years. Observations on the time of appearance of new lesions in the crops and the time at which potted plants became infected suggested that night temperatures and humidities were important factors in determining spread. Two applications of copper-containing sprays increased the yield of tubers by 1·5 tons per acre. Of five materials compared for haulm destruction, sulphuric acid was the most effective : *P. infestans* was sometimes still active on stems that appeared dead.

As a preliminary to starting experiments to determine the effects of powdery mildew (*Erysiphe graminis*) on the yield of cereals, the protective actions of various fungicides were studied, and lime sulphur was found to have a beneficial effect lasting for a fortnight.

BIOCHEMISTRY DEPARTMENT

By N. W. Pirie

Nucleoproteins from Normal and Virus Infected Leaves

(E. M. Holden, G. Parker, N. W. Pirie)

We have for long been concerned with the purification of plant viruses, that is with ascertaining what is the minimum chemical complexity needed for a preparation to initiate infection in a susceptible plant. Recently we have become more interested in examining the state in which viruses normally exist in the leaf and in the changes that they undergo during the process of purification. This work has made it more urgent than hitherto to study the unstable components of extracts of the normal leaf, and the controls for much of the experimentation with which we have been concerned during the past 16 years are now, perhaps a little belatedly, being done.

The sap from uninfected young tobacco leaves growing under good nutritional conditions contains up to 3 g./l. of an unstable nucleoprotein that can be sedimented readily on the ultracentrifuge at 50,000 g. Making the usual assumptions therefore, it has a particle weight similar to that of tobacco mosaic virus, and more or less spherical particles of the expected size appear on the electron micrograms. This material disappears from, or at any rate is less readily isolable from, old leaves, ill-nourished leaves, or infected leaves. It is destroyed by a few hours' exposure to leaf sap at room temperature, or by a few days at 0°, but is much more stable in the absence of sap components and of salts.

The protein has an intrinsic biochemical interest because it is a substantial component of the leaf, because it carries with it the enzymes necessary for its own destruction, and because it is responsive to the physiological state of the leaf. By using the known properties of the isolated protein as a guide an attempt is being made to see how much of the phosphorus of the fibrous leaf residues and of the "chloroplast" fraction centrifuged from sap is made up of this material. Similar materials have been prepared from leaves of other plants and when suitable opportunities occur, we hope to examine its composition and behaviour carefully. Because of its instability it will not be a significant constituent of purified preparations of the more stable viruses but, when our present techniques are used, it will contaminate all preparations made by methods designed to separate a virus in its original state.

Some order has now been introduced into our studies of the Rothamsted strain of tobacco-necrosis virus. Extracts from infected leaves contain, besides the normal nucleoprotein mentioned above, a specific non-infective nucleoprotein and material which we look on as virus, partly in an active and partly in an inhibited state. On standing in sap there is at first an increase in the infectivity of the subsequently isolated virus and then a diminution in infectivity. We have examined both phenomena and suggest that much of the virus in the infected but undamaged cell may be non-infective. If this can be substantiated we have in this plant virus a phenomenon comparable to the "masking" that is found with some animal

viruses and with the lysogenic strains of bacteriophage infected bacteria. The essential difference is that the leaf sap itself contains systems able to bring about the unmasking.

Enzyme Mechanisms involved in Manganese Oxidation

(R. H. Kenten, P. J. G. Mann)

It has previously been shown that Mn^{++} can be oxidized by peroxidase systems. The oxidation of Mn^{++} in plants *in vivo* by such systems depends on the production of hydrogen peroxide by the plant tissues. During the year an attempt has been made to demonstrate the presence of H_2O_2 producing enzyme systems in plant extracts and to bring about manganese oxidation by linking these and other known hydrogen peroxide producing enzyme systems with peroxidase systems in presence of Mn^{++}.

Two of the hydrogen peroxide producing enzymes have so far been identified. One is an amine oxidase, the other is an aldehyde oxidase which has not previously been described.

The crude extracts of pea seedlings and partially purified enzyme preparations obtained from such extracts rapidly attack diamines such as putrescine and cadaverine and monoamines such as β-phenylethylamine and indolethylamine. So far it has not been possible to demostrate the presence of this enzyme in extracts of other plants. A quantitative study has been made of the total O_2 uptake during the oxidation of the amines and of the products of oxidation. In these experiments phenyl-ethylamine and putrescine have generally been used as representatives of the mono- and di-amines attacked. The results suggest that the primary attack on the amines is an oxidative deamination according to the equation :

$$R.CH_2NH_2 + H_2O + O_2 \longrightarrow R.CHO + H_2O_2 + NH_3$$

The formation of hydrogen peroxide during the oxidation of the amines was shown by the effect of catalase on the total oxygen uptake and by the coupled oxidation both of the phenols hydroquinone and p-cresol by peroxidase, and of ethanol in presence of added catalase. The formation of aldehydes during the oxidation was shown by bisulphite titration and, in the case of β-phenylethylamine, by the isolation of phenylacetaldehyde as the 2 : 4-dinitrophenylhydrazone.

An enzyme which catalyses the oxidation of phenylacetaldehyde but not that of benzaldehyde, phenyl propionaldehyde or the n- and branched chain aliphatic aldehydes has been found in extracts of many higher plants. Hydrogen peroxide is formed during the course of the oxidation, but the nature of the other oxidation products has not yet been established. By analogy with the known aldehyde oxidases it appears probable that phenylacetaldehyde would be oxidized to phenylacetic acid. It is possible that the natural substrate of this enzyme is indoleacetaldehyde which is presumably formed by the action of amine oxidase on indolethylamine or from indolepyruvic acid by decarboxylation. Preliminary tests suggest that indoleacetic acid is formed by the combined action of the amine and aldehyde oxidase on indolethylamine, but owing to the

presence of indoleacetic acid oxidase in the enzyme preparations it has so far not been possible to demonstrate this with certainty.

Some progress has been made in reconstructing from partially purified enzyme preparations the type of system causing manganese oxidation in plant extracts. Manganese oxidation has been demonstrated in pyrophosphate buffers when H_2O_2 producing enzyme systems such as amine oxidase, aldehyde oxidase, xanthine oxidase, and amino acid oxidase are linked with peroxidase systems in presence of Mn^{++}.

The Composition of Fungal Mycelia

(W. R. Smithies, M. V. Tracey)

During the past year work has been started which is designed to throw some light on the nature of soil organic matter. We are approaching the problem by way of a study of chemical nature of the resistant residues of soil inhabiting bacteria and funguses. It seems likely that if we know more about the material from which soil organic matter is derived the investigation could proceed on more rational grounds than it has in the past. To gain experience with fungal material, work has been started on *Penicillium griseofulvum* mycelium which we can get in bulk from Imperial Chemical Industries. At a later date, when we have studied a few easily procured funguses, and when we know what sort of material to look for, work will be done on deliberately grown cultures of soil organisms.

With this organism about half the mycelial N is protein and 10-12 per cent is in the form of amino sugars behaving like glucosamine. Amino sugars are a characteristic feature of other fungal mycelia whereas they are relatively unimportant in plant residues. The identification of amino-sugars, the determination of their mode of linkage, and the study of the extraction and stability of the amino-sugar compounds under conditions similar to those in soil, is therefore an important part of our present and projected work.

Technological production of Leaf Protein

(M. L. Barnes, D. S. Miller, N. W. Pirie)

Work on the large scale production of leaf protein is mainly done at the Grassland Research Station, but some ancillary small scale work is done here. We have designed, and now have running a mill that deals satisfactorily with every lush agricultural leaf we have tried in it (about 10), and produces a pulp at the rate of about 1 ton (wet weight) per hour, from which liquor carrying 30-60 per cent of the leaf protein can be expressed. We have designed several continuously acting arrangements to press out the liquor from this ground mass, and the latest one, made at the National Institute of Agricultural Engineering, is reasonably satisfactory, though we see that more work is still necessary on this aspect of the problem. Heat coagulation and separation of the protein present no particular problems. The unit should be able to produce protein at a reasonable rate during the spring of 1951.

NEMATOLOGY DEPARTMENT

By T. Goodey

General

Dr. T. Goodey attended the 7th International Botanical Congress, Stockholm, 12-20 July, 1950, and delivered a paper in the Agronomy/Phytopathology Section on " Oats and varietal susceptibility to stem eelworm infestation." In passing through Denmark on the way to Sweden a visit was paid to the State Plant Pathological Station at Lyngby to see the work in progress on plant-infesting nematodes under the care of Dr. Prosper Bovien. During the course of the Congress, contact was made with Dr. Olaf Ahlberg, of the Statens Växtskyddanstalt, who has done much work on the occurrence and distribution of the potato root eelworm, *Heterodera rostochiensis*, in Sweden. On the occasion of the Congress Excursion to Uppsala special attention was given to the work being done at the Sveriges Utsädesförening on the selection and testing of races of red clover for resistance to clover eelworm, *Ditylenchus dipsaci*. These studies are largely carried out by Mr. Sven Bingefors who worked for two months in our department last year.

Members of the staff of the department are frequently consulted by the National Agricultural Advisory Service and other workers for advice on matters connected with nematode infestations and much time has been given during the year to the identification of eelworms, the diagnosis of eelworm infestations and to help in the planning of field and plot experiments where nematodes are involved.

During the year three temporary workers from abroad each spent periods of about one month in the department learning our nematological methods. These were Dr. J. W. Seinhorst of the Institute for Phytopathological Research, Wageningen, Holland; Monsieur M. Ritter of the Station Centrale de Zoologie Agricole, Route de Saint-Cyr, Versailles, France, and Ir. R. H. Kips of the Rijkslandbouwhogeschool, Ghent, Belgium.

An exhibit illustrating stem eelworm infestation of onion, known as " bloat," was staged for the Chelsea Flower Show in May, 1950, in the preparation of this much valuable work was done by Mr. C. C. Doncaster and Mr. J. B. Goodey.

These two have also collaborated in the production of a general-purpose photographic apparatus which has been mainly constructed from second-hand equipment already in the department. The apparatus is used for lower-power photomicrography where a wide evenly illuminated field is required and it is also of use for obtaining pictures of known greater magnifications. An enlarger attachment for use with it is also under construction.

Research carried out by the members of the staff falls naturally, as in previous years, into two main sections: (1) problems connected with plant infestations by eelworms belonging to the families Tylenchidae and Aphelenchidae and soil nematodes generally (Dr. T. Goodey, Dr. Mary T. Franklin and Mr. J. B. Goodey), (2) problems connected with root-infesting nematodes belonging to the family Heteroderidae (Dr. B. G. Peters, Mr. D. W. Fenwick and Mr. C. C. Doncaster).

Tylenchidae and Aphelenchidae

Tylenchidae

Dr. Goodey has continued his investigations on the stem eelworm, *Ditylenchus dipsaci*, particularly on the races infesting teasel, oats and red clover. Many inoculation experiments were carried out to test the range of hosts susceptible to attack from these and other races of the parasite. Particular attention was devoted to studies on the oat race of *D. dipsaci* with a view to finding Spring oat varieties resistant to attack, and some progress was made though difficulty was experienced in the influence of soil type and temperature on infestation and manifestation of symptoms.

In the course of this work it was found that the oat race of the parasite can attack and seriously injure rye. This finding from pot experiments confirms observations made by a National Agricultural Advisory Service Officer in North Wales where rye was badly affected in a field known to be infested with the oat race and indicates that the oat and rye races of the stem eelworm are most probably identical; a fact which seems to be recognized in Germany and Holland. The oat race also infests vetches, and pot experiments carried out during the year have proved its ability seriously to injure the vetches *Vicia villosa* and *V. sativa*. A paper embodying these results is in course of publication.

Mr. J. B. Goodey reports that work has continued on the plant parasitic species of *Ditylenchus*. The potato-tuber eelworm, *D. destructor* has been found in the field causing light brown lesions, somewhat similar to those on Mint, on the rhizomes of a new host, *Stachys palustris*, which is a common weed of some Fenland potato fields. The experimental infestation of this plant has also been successfully carried out. Observations in the field have shown that the presence of *Mentha arvensis* in particular, is probably to be correlated with the continuing infestation of *D. destructor*. These observations have been further supported by the failure to maintain an infestation on a plot of bulbous Iris, which has no Mint growing on it. The attempt is being made again with the addition of a cover of *Mentha arvensis*.

In 1895 and 1939, the Hop plant, *Humulus lupulus*, was recorded as a host of *D. dipsaci*, a peculiarity of both reports being that the infestations were confined to the roots. Re-examination of the 1939 material which was in this department showed that the eelworms had all the characteristics of *D. destructor*. An experimental transfer was successfully made from potato to pieces of hop roots with the setting up of typical root lesions. Later, when diseased hop sets from the site of the 1939 material, near Sittingbourne, Kent, were obtained, transfers to mint, bulbous iris and potato were successful as well as further transfers from mint to hop.

Lilac, *Syringa vulgaris*, has also been recorded as having its roots attacked by *D. dipsaci*. Again, it has now been shown that *D. destructor* is the eelworm responsible and transfer has been effected from potato to lilac roots and back again to patato.

Experimental infestation of *Begonia tuberhybrida*, *Tigridia pavonia* and *Gladiolus hybridus* by *D. destructor* and the Narcissus race of *D. dipsaci* have shown that both eelworms can attack these plants. On *Begonia*, *D. dipsaci* caused lesions and ultimately shrivelling of the leaves whilst *D. destructor* had no apparent effec

on the growing plant. Small brownish blotches were produced on the leaves and leaf bases of *Tigridia* by both parasites but those caused by *D. destructor* were confined to the underground parts of the plant. *D. dipsaci* caused considerable malformation of *Gladiolus* leaves and eelworms were plentiful in them; eelworms were also found in some of the seed pods. *D. destructor*, on the other hand, caused no apparent damage but could live and reproduce in the leaf bases so that *Gladiolus* might be termed a harbourer of *D. destructor*. A paper on these investigations is being prepared. During the work on *D. destructor* it became apparent that the host plant was influencing the size of eelworms comprising the parasitic population. Numerous individuals from different populations were measured and it was found, for instance, that mean lengths of males or females of different populations differed significantly from one another. This work will shortly be written up.

Observations on the attack of *D. dipsaci* on strawberry have continued and it has been shown experimentally that populations from teasel, oats, onion, red clover, narcissus and rye will all infest most of the popular varieties of strawberry in cultivation to-day. Investigations into the ways in which infestation is maintained have been carried out, and it is suggested that the discontinuity of infestation seen in some plants can be related to the way in which infestation originates. A paper embodying these findings has been prepared.

Further observations have been made on a Hyphomycete referred to the genus *Cephalosporium* acting as a hyper-parasite of *D. dipsaci* infesting *Calceolaria*. A paper on these findings has been accepted for publication.

A new species of *Rotylenchus* attacking and aiding in the destruction of the roots of a species of hothouse *Hippeastrum* (Amaryllis) has been discovered and will be described shortly. The eelworm appears to be a parthenogenetic species since only females were found and no evidence of the presence of males was apparent. An interesting feature of the infestation was the occurrence of a secondary piliferous layer on the *Hippeastrum* roots, a condition not previously reported, as far as can be ascertained. A specimen of this eelworm was found attacked by a nematode-catching fungus of the genus *Harposporium*.

Investigations on the relationships of *Hoplolaimus uniformis* and its effects on the young seedlings of Sitka spruce, *Picea sitchensis*, are still continuing. Several eelworms attacked by fungi have been found. In one case attack was by a species of *Arthrobotrys* and in other cases by at least two different fungi which have not so far been identified; attempts to culture them on artificial media have been unsuccessful. Another nematode, an as yet unidentified species of *Trichodorus*, has also been found associated with the Sitka spruce seedling roots.

Aphelenchidae

Dr. Mary T. Franklin reports that work has been continued on the three species of *Aphelenchoides* well known as parasites of cultivated plants, namely *Aph. fragariae*, *Aph. ritzema-bosi* and *Aph. ribes*. A fourth species has been studied which, during the past wet season, has apparently been responsible for damage to

Caucasian scabious on at least three nurseries. This is provisionally identified as *Aph. parietinus*, but it differs morphologically in some respects from that species as originally described by Bastian in 1865.

Two new host plants of *Aph. fragariae*, namely mint (*Mentha spicata*) and scabious (*Scabiosa caucasica*), have been added to the collection of host plants of this species on the museum plot. Clean bulbs of *Lilium regale* and *L. henryi*, planted amongst the infested violets on this plot, became infested with the same nematode.

A number of infection tests with *Aph. ritzema-bosi* and *Aph. ribes* on various hosts has strengthened the evidence for the identity of these two nematode species. A new method of inoculation, used on chrysanthemums, has been developed and gives positive results in 7-14 days. Examinations are being made of weeds associated with both chrysanthemums and black currants infested with eelworms to find out to what extent the weeds can harbour the parasite in the absence of the cultivated hosts.

Throughout the year infested blackcurrant bushes have been examined and invasion of the next year's buds has been found to take place at a very early stage. Adult *Aph. ribes* have been found capable in the laboratory of travelling at least 11 inches up a damp cotton wick down which there is a slow trickle of water. Larvae will travel, or are carried, down a similar wick. Migration over infested bushes in damp weather thus offers no difficulties. The warm-water treatments of unrooted blackcurrant cuttings started last year had no apparent detrimental effects on the cuttings, which produced satisfactory plants in the greenhouse. The buds, however, were stimulated to develop early, which might prove dangerous to cuttings grown out-of-doors where they are not protected from frost. More warm-water treatments were therefore carried out this year in November and the cuttings have been planted outside. Eight different varieties of blackcurrant have been treated at 46°C. for 25 minutes, 48°C. for 15 minutes, and 50°C. for 10 minutes.

A visit was paid to one of the nurseries where Scabious has been damaged by eelworm and material brought back for study of the parasites. These did not entirely agree with the original description of *Aph. parietinus* given by Bastian in 1865 of nematodes which he found in the lichen *Parmelia* (now *Xanthoria*) *parietina* growing on walls at Broadmoor, Berks. *Aph. parietinus*, also, has not generally been considered to be parasitic. In order to get a clearer idea of this species specimens of *Xanthoria parietina* were brought from Broadmoor and the nematodes in them are being examined.

Heteroderidae

Dr. Peters reports as follows :

Concerning population studies on *Heterodera rostochiensis*, a long-term experiment on the effect of edaphic factors on the growth of eelworm populations (and the effect of the latter on the potato plant) is in its second year, in 8-litre, glazed, cylindrical pots, in which a heavy clay is factorially modified by the addition of sand, peat, compost and artificials (the last two renewed annually). Starting with a light infestation of the eelworm, the first season showed a 20-fold increase in cysts per gm. of dry soil, and a 35-fold

increase in eggs per gm., with significant effects from sand (negative) and peat (positive). The potatoes, on the other hand, responded significantly to compost and artificials. This experiment is expected to throw light on soil conditions favourable and unfavourable to the eelworm, and on the diversion of plant foods from tuber production to eelworm production.

The movements of potato root eelworm larvae through soil are being investigated, the vertical and horizontal components separately. First results show that movements are probably limited to a few inches in any direction, in one season, and that the larvae move upwards (against top watering) more readily than downwards (against bottom watering). Two factors limiting movement, pore space and water content of soil are being investigated in greater detail before proceeding with further migration problems.

Counts of potato root eelworm larvae hatching from cysts, recovered from soils used in the 1949 series of pot tests of nematicides, are of some interest. Two chlorophenol compounds, D-D mixture and ethylene dibromide had been injected into duplicate 8-litre pots of soil at 0, 1, 4 and 16 ml. per pot. Larvae per gramme of soil were estimated 7 weeks after injection (Y samples) and again after growing a potato in each pot (Z samples). The Y sample showed no effect from the cholorophenols, the vapour pressure of which is presumably too low for use as fumigants ; $L.D._{50}$ for D-D was about 0·4 ml. and for ethylene dibromide about 2·3 ml. per pot. A comparison of Z with Y samples showed a multiplication factor of 5·4 for larvae in the 8 control pots. The factor was reduced for D-D and ethylene dibromide at the 4 ml. dosage, negligibly small at 16 ml., but *increased* at the 1 ml. dosage : 8·0 for ethylene dibromide and 17·6 for D-D. This was correlated with an increased yield of tubers at this dosage.

Pot experiments have continued in 1950, using D-D mixture, ethylene dibromide, methallyl, chloride, dichloroethyl ether, chlorophenols and cresols (Sterizal). The D-D series covers the comparison of the same dosage used neat and emulsified with Triton N.100. Here also, effects on subsequently grown potatoes are being observed ; D-D at high rates and ethylene dibromide are especially phytocidal. Tests of the recent bromochloropropylene mixture will be carried out next season.

Mr. Fenwick has again co-operated in the joint experiment with the West Farmers' Co-operative and Shell Chemicals Ltd., on the effects of annually repeated injections of D-D on potato root eelworm, at Moulton and Prickwillow. This experiment has now terminated. Eelworm counts from the final samples are not yet available, but the final yields show a significant improvement from D-D at 800 lb. and 400 lb. per acre at Moulton. At Prickwillow the improvement was significant statistically but not economically.

Work on the use of the vinegar eelworm as a test animal in screening tests of nematicides has continued. Analysis of counts of some 60,000 worms has shown that too frequently the variance between parallel counts is higher than would be expected on Poisson theory, and the reason for this has been found. Some 20 experiments on methods of culturing are being summarized for publication. In connection with the sorption by the worms of nematicidal substances, a method has been found for estimating the

surface, volume and mass of a single worm, and (by correlating these parameters with worm-length) of a culture of worms.

Analysis of Mr. Fenwick's larval counts of the 1948 soil samples from Barnfield (*Heterodera schachtii*) shows the following. The general mean, at 4·88 larvae per gm. of soil, is lower (but not significantly so) than that of the 1946 samples; thus there is no evidence that the population is increasing. The infestation has now fairly well covered the field, but is far from random. Counts on the " no manures " lots and " no nitrogen " series are significantly lower than all others. Counts on the " nitrate of soda " series are significantly higher than on the " sulphate of ammonia " series, and those on the " superphosphate only " plots lower than on the plots with complete minerals, P and K, and P with $MgSO_4$ and NaCl. There is again a significant correlation ($r = \cdot 6155$) between larval count and the mean yield (1904-1940). Using the yields to forecast the counts, the treatment effects are similar to those just mentioned; in addition, the counts from the dunged plots are slightly below expectation.

Assistance has been given to Mr. Doncaster in carrying out tests with Pestox III against *Heterodera marioni* and *Heterodera rostochiensis*; these are still in progress.

Mr. D. W. Fenwick reports that the use of hypochlorite as a hatching agent for distinguishing between living and dead larvae of *Heterodera rostochiensis* has proved to be valueless. There appears to be little hope at present of using it, or any other short method, in place of the root diffusate technique, and further research into the method has been abandoned.

A new technique has consequently been evolved for the conduct of a shortened form of hatching test. Use is made of the fact that that cumulative hatching curve plotted against log-time is a sigmoid and is therefore symmetrical about its own point of inflection. The method has been written up and accepted for publication.

The effect of physical conditions on larval emergence has been investigated in detail and a record of this work has also been accepted for publication. Presoaking of cysts for about 12 days prior to immersion in diffusate has the effect of speeding up hatching very considerably but little, if any, effect is discernible on the total number of larvae which ultimately emerge. Temperatures over 30°C. inhibit hatching but below this temperature variations between 15 and 25°C. are without effect on total emergence, although rise of temperature is accompanied by an increase in hatching rate. Volume of diffusate per cyst is without apparent effect on either total hatch or rate of hatching. pH fluctuations between pH 4·0 and pH 8·0 are also without effect. The effect of dilution of diffusate is interesting in that when hatch, expressed as total larvae emerging, is plotted against dilution, expressed logarithmically, a linear relationship is obtained and it is reasonable to draw the tentative conclusion that the number of larvae emerging from a given sample of a single stock of cysts is directly proportional to the logarithm of the concentration of the diffusate. Use is being made of this linear relationship, for the biossay of diffusate.

The promising results obtained by using purely biological methods of biossay are in marked contrast to the disappointing

results obtained using anhydrotetronic acid. This chemical appears to be markedly inconstant from sample to sample, moreover the activity of any given sample is variable and no further investigations into its activity are contemplated.

Preliminary experiments have been conducted on the breakdown of root diffusate in soil. It has been found that after four days following on the application of a single dose of potato root diffusate, 90 per cent of it had undergone breakdown. Moreover, examination of cysts recovered from the soil showed that larval emergence was restricted to the four days prior to this breakdown, and amounted to approximately 20 per cent. Further experiments are in progress to investigate the factors influencing this breakdown.

The hatching effect of root diffusates produced by *Solanum nigrum* is under investigation. The diffusate has been shown to be active in inducing larval emergence and it is hoped to investigate the effect of growing this plant as a trap crop.

Experiments have been conducted on the effect of temperature on the development of the potato root eelworm. It has been found that a rise in temperature above 21°C. is unfavourable to the continued multiplication of the parasite. At 32°C. development is almost inhibited, and penetration of the larvae into the roots is checked, as is further development within the roots. The latter effect is apparently the more important. These experiments form the subject of a paper accepted for publication.

A series of experiments is in progress on fluctuations in eelworm populations during a growing season. This problem has been approached from two points of view, (a) the estimation of gross changes occurring in the whole population ; (b) the rate of penetration of the larvae into the root. Preliminary experiments conducted on the gross changes in population indicate that the number of cysts in an infected soil remains constant for the first four or five weeks of the plant's growth, then rises steadily as the new cysts are formed. The fluctuations in the larval population seem to depend on the size of pot used. In 6 in. pots the number of larvae per cyst falls to approximately 20 per cent of their original value in the first few weeks, thereafter rising rapidly in response to the formation of new cysts. In larger pots this effect is much less marked, the initial fall being in the neighbourhood of 10-20 per cent and the subsequent rise in larval content following on the formation of new cysts is less marked. This effect seems to indicate that root diffusate produced by the plant is only very local in its effect, and that in the larger pots used the majority of the cysts present never come into contact with the root diffusate. If this indication is correct, then it would appear unlikely that trap-cropping with potatoes would be of very much use in reducing the level of infestation present in a plot of land.

The rate of penetration of the larvae into roots has been studied by growing potatoes in infested soil and then transplanting at fixed times to clean soil : the number of cysts produced at the end of the season in this soil should then be a measure of the number of larvae which originally entered the root up to the time of transplanting. A surprising feature of these experiments is the large amount of penetration which occurs in the few days between planting a chitted tuber and its emergence through the soil. Many plants when trans-

planted at the time of breakthrough yielded over 3,000 cysts when later examined. It is interesting to record also that the maximum yield of new cysts occurred when potatoes were transplanted at breakthrough; plants which were transplanted later and which should presumably contain more larvae were found to yield fewer cysts.

In conjunction with Miss E. Reid, a new technique for measuring infestation on a growing plant by estimating the density of white cysts produced has been evolved. The method is capable of estimating this density to a known degree of accuracy, and results can be expressed as number of white cysts per gramme of root. The method has been written up and submitted in the form of a letter to *Nature*.

A new type of McMaster slide has been evolved which accommodates a 1cc. sample with greater security than does the original type. It is possible to mount up to six counting chambers on a single unit. The design of the slide and its method of preparation have been described and submitted for publication.

Co-operation with Dr. H. C. Gough, of the Cambridge National Agricultural Advisory Service, on long-term changes in eelworm population during different crop rotations on different soils is continuing.

Experiments in conjunction with Dr. B. G. Peters on the effect of repeated annual injections with D-D have now been completed and the final results are being analyzed. These experiments were rendered possible by the co-operation of the West Norfolk Farmers' Co-operative, and it is now intended to carry out a further series of trials with the object of investigating the effect of introducing single and repeated D-D injections into different phases of a four course rotation.

Mr. C. C. Doncaster reports that investigations have been begun on the morphology of tomato and potato roots which have been parasitized by *Heteridera rostochiensis* and by *Heterodera marioni*. Tomatoes and potatoes were each infested with the Root-knot Nematode and with the Potato-root Nematode and samples of infested plants were removed and fixed at frequent intervals until advanced effects of parasitism has developed.

A detailed study of whole and sectioned material is being carried out in order to observe the different histological and morphological reactions of the two plants to each parasite.

In collaboration with Dr. B. G. Peters investigations on the use of systemic insecticides as nematicides have been started. Pestox III (bis(bis dimethylamino phosphonous)anhydride) has been tested on tomatoes, brassicas and nasturtiums to find a sub-phytotoxic dose which may be employed in tests against *H. marioni* and *H. rostochiensis*. These tests are now in operation. Preliminary *in vitro* tests on the effect of Pestox III on the hatching of cysts of *H. rostochiensis* and of egg-masses of *H. marioni* indicate that the substance merely retards hatching and that eggs and cysts are not killed even by 24 hours immersion in a 2 per cent solution of Pestox III.

ENTOMOLOGY DEPARTMENT

By C. B. Williams

The reduction of damage by insect pests can be either direct—by insecticides and other chemical methods, or indirect—by agricultural methods and biological control, just as in Medicine there are the curative, and preventative or " Public Health " services. As there is in Rothamsted a separate Insecticides Department, the work of the Entomology Department is definitely biased towards indirect methods.

The staff consists of five Scientific Officers, two scholarship students of the Agricultural Research Council, four Experimental Officers and two overseas research students.

The work can be roughly divided into :

(a) Fundamental work on the causes of insect outbreaks.

(b) Special problems of particular pests or crops.

Fundamental Work on the Causes of Insect Outbreaks

The effect of weather conditions on the activity and abundance of insects (C. B. Williams, R. A. French and B. P. Singh)

Measurements of the changes in insect numbers have been collected for many years, chiefly by means of traps. Light traps have been the standard, but bait traps have been tried, and suction traps have recently been developed.

The figures have been analyzed statistically and it has been possible to calculate the effect of different weather conditions on the immediate activity of the insects, and also on the size of the future populations. Results so far show that it is possible to account for 70 per cent of the variance of the total insect population in summer and autumn by the effect of the rainfall and temperature of the three previous months. The work is throwing considerable light on the relative importance of weather, parasites, and food supply in determining outbreaks. It is proposed to carry on with the analysis of special groups of insects, and of certain species which are sufficiently abundant for statistical analysis. A much more efficient form of light trap, using a mercury vapour lamp, has recently been tested and with this it will be possible to get much larger numbers of certain species.

Mr. Singh is using suction traps (designed by Dr. Johnson) to obtain samples for comparison with the light trap results. The suction trap also makes possible the comparison of day and night conditions.

The relative abundance of different species of insects (C. B. Williams and R. A. French)

The relative abundance of different species of insects and other animals in mixed wild populations, is also being studied, chiefly from the trap samples, and it is found to be consistent with some relatively simple mathematical laws. For many years there has been talk of the " Balance of Nature," now we seem to be beginning to understand what it means. Two alternative mathematical series are at present being tested—the logarithmic series and the log-

normal series. With small samples the theoretical differences are very small, it is only with large samples that the differences will be measurable. The Statistical Department are co-operating with some fundamental work on sampling from a log-normal distribution.

Arising out of this work has come the conception of the " Diversity " of a population as an important ecological factor, which is found to be the basis of many previously ill-understood properties of populations ; such as, for example, the distribution of plant species in quadrats. Work is now directed to getting very large samples of animal populations from a limited area in a short time. The new traps will help considerably in this. With such samples it should be possible to distinguish between the validity of the two alternative formulae.

Migration and drift

The distances which insects can regularly move is of fundamental importance in all questions of insect control and of quarantine for insect pests. Most recommendations about the rotation of crops seem to be based, so far as insects are concerned, on a complete misunderstanding of their capabilities of distribution. Our work is divided into two sections—*Migration* (C. B. Williams) and *Drift* (C. G. Johnson).

At Rothamsted *migration* has been studied in all insects (except locusts) from all parts of the world, but the majority of records are in the Lepidoptera. Insects can migrate of their own accord, by their own power, and irrespective of the direction of the wind, distances frequently over 100 miles and occasionally over 1,000 miles. Our Cabbage White Butterflies come over the North Sea from Central Europe, and our Silver-Y Moth and many others come from the Mediterranean area. Work consists at the moment chiefly of acting as a centre for the collection and study of records. A return flight has been shown by our work to exist in many species but the problem of " orientation " has not yet been solved. A book on the Migration of Insects is in preparation for the " New Naturalist " Series.

Related to migration is the problem of *Phase Colouring in Caterpillars* (D. B. Long).

About 30 years ago Uvarov discovered that grasshoppers and locusts can exist in two " phases " or forms which differ in colour, relative dimensions, activity, behaviour and metabolic rate from each other. The " Gregaria," dark-coloured phase is produced as a result of crowding, and the pale " Solitaria " phase by isolation of the individuals in the early larval stages.

About six years ago phase differences were found in three South African caterpillars by Faure.

We have recently found definite evidence of phase differences in the larvae of the Silver-Y Moth (*Plusia gamma*) an immigrant noctuid moth which is at times a pest of field peas, beans and other crops. Crowded larvae become dark-coloured and active, isolated larvae become pale and inactive. There are also associated differences in rate of development and colour and state of maturity of the adult moths. It is curious that these phases have been found almost entirely in migratory insects.

The work is continuing and Long is trying to find similar phase differences in other caterpillars, including those of non-migratory species.

Drift of insects (C. G. Johnson and L. R. Taylor). Dr. Johnson has studied for some years the drift of small insects, especially Aphididae, in air currents, and particularly their distribution in the upper air. Trap nets attached to the cables of barrage balloons, at Cardington, have resulted in the capture, on warm summer days, of up to ten or twenty living Aphididae per hour in a net three feet across. Thus the distances that thousands of these smaller insects can travel must normally be measured in tens or hundreds of miles.

Owing to the unreliability of simple nets at low wind speed, suction traps have been developed in which air is sucked or blown through a net by means of an electric fan. Thus a fixed amount of air is sampled each hour irrespective of wind velocity. These traps are being specially used to find the population density in the air at night when wind speeds are usually very low. Similar traps have also been used at ground level to study the activity of Aphids. It seems that in many species there is a double peak of activity in the day, one in the morning and one in the early evening. Special studies have been made on the Aphididae with the help of Mr. Judenko and Mr. V. Eastop; on the lacewings (*Chrysopidae*) with Mr. C. J. Banks; and the Heteroptera with Mr. L. R. Southwood.

Suction traps have also been made, loaned and maintained for Dr. Broadbent's work on Aphididae, for Dr. Hull's work on sugar-beet near Bury St. Edmunds; and for red spider work at East Malling.

Consultation has been established with the Blackburn and General Aircraft Company for the problem of small insects sticking to the surface of high speed aircraft and causing surface drag.

Biological control

The interrelation of host, parasite and predator relationships was being studied by Mr. Banks, in the special case of Aphididae, and their ladybird, hover-fly and lace-wing enemies.

Unfortunately Mr. Banks has been away ill for over a year, but he returned in October and this work will be resumed and extended.

Population changes in Gall Midges (H. F. Barnes)

For twenty-four years Dr. Barnes has measured the population density of two gall midges which attack the wheat on Broadbalk. The results indicate a periodic abundance and scarcity. Years of peak abundance were 1931, 1936, 1941 and 1946. The year 1951 is forecast to be another year of abundance. Similar series of observation are very rare, but very necessary for the understanding of population fluctuations.

Dr. Barnes has shown that the midges can remain underground for as long as nine years and this long diapause may perhaps have something to do with the periodic outbreaks.

Population studies in Aphididae (C. G. Johnson)

The estimation of bean-aphis infestation by dilution and photographic methods, and the pattern of aphis infestation of fields in

relation to wind direction have been under investigation, together with a general study of population ecology.

Special Problems

Soil invertebrates and their relation to soil fertility (F. Raw, G. O. Evans, J. E. Satchell and B. R. Lawrence).

(a) A grant from the Forestry Commission has enabled Evans to study the relation of soil arthropods to soil fertility with special reference to forest soils and forest litter. With soils with such a high percentage of vegetation the flotation method does not work so well and Evans is now using Tullgren's modification of Berlese funnels. In coniferous and deciduous stands at Ampthill and Woburn he has found populations reaching 400 million insects (chiefly *Collembola*) and 700 million mites per acre. Identification of these is a major problem. The soil mites—in fact mites in general—have been so little studied in this country that Evans has had to do a considerable amount of work on this group. He is also making life history studies of representative species. It is a long and difficult problem and only slow progress can be made.

(b) *Insects and dung*. B. R. Lawrence is making a study of the insect fauna of dung, and the rate of breakdown by different types of coprophagous insects.

(c) *Earthworms*. Considerable progress was made in the study of earthworms and their relation to soil fertility by Dr. A. C. Evans a few years ago. The different species were sorted out and methods were found to identify most of the immature forms. The species were partly sorted according to their ecological requirements, and studies were made in the rate of turnover of soil by those species which form worm-casts on the surface.

Since A. C. Evans left, the work has been carried on by J. E. Satchell. His problem has been chiefly that of developing a new technique for bringing earthworms to the surface. A. C. Evans used the method of watering with a dilute solution of potassium permanganate. The new method now being tested makes use of an electric current. It brings up more worms per square foot than the potassium permanganate method, and in particular is more efficient in bringing up deep living species such as *Lumbricus terrestris*. Worms brought to the surface are unharmed, whereas using potassium permanganate the worms die rapidly after surfacing. A great advantage is that it is also applicable to areas—such as Park Grass—where it is not desirable to use chemicals. It is hoped later to have a portable generating set which can be used for field sampling.

The general result of our work to the present is that certain species of earthworms are of considerable value in permanent grassland by turning over and aerating the soil, but that in arable land their value is negligible.

(d) *Wireworms*. Dr. Raw has collaborated with the Insecticides department in the wireworm experiment in Hoosfield by sampling the plots at intervals to test the effect of the treatments on the wireworm population. The large soil washing machine designed at Cambridge and tested at Rothamsted has been overhauled with the help of Mr. French, and now that this is in operation future soil work will be facilitated. The sampling to date shows that the wire-

worm population on all plots has fallen considerably as a result of cultivations and this fall has masked any treatment effects. It may be, however, that the treatments, which had marked results as measured by yields, acted as repellants, and a fall in population may not follow or may only follow after some time as a result of starvation.

Though advances have been made in chemical control of wireworms, they remain a major problem. There is a great need for more information about their general ecology, in particular the factors affecting their distribution and dispersal and the build-up of populations in leys. In this connection two lines of work are in hand.

The changes in wireworm populations are being followed in the ley-arable experiments on Highfield and Fosters, beginning on the one hand with the high population characteristic of permanent grassland and on the other hand with the low population characteristic of old arable land. This is a long-term study and it is hoped to be able to extend it to leys of longer duration and to other soil types

Factors affecting the distribution and dispersal of wireworms are being studied in Park Grass. A limiting factor in this work is the small amount of sampling permitted. The data collected so far do not permit of any conclusions being drawn beyond the tentative suggestion that the percentage of weeds is important. In this work use is being made of the vegetation analyses made by the Botany Department; more data on the physical environment would be useful.

The work on Park Grass is being extended to other arthropod groups. Sampling necessitates modification in techniques as the present flotation method which is accurate for estimation of number of arthropods larger than 2 mm. is not accurate for smaller forms such as mites and *Collembola*; Berlese funnels are subject to empirical errors especially when used for heavy clays. The flotation technique holds the greater prospect of final application, and modified chemical and physical means of dispersing the soil prior to flotation are being investigated.

Gall Midges of economic importance (H. F. Barnes and B. M. Stokes)

Dr. Barnes has been for many years a recognized authority on the group of Diptera known as the *Cecidomidae* or Gall Midges, which include a number of very serious pests of crops. He is writing a monograph of the habits and control of these insects throughout the world. Of this, five volumes out of a projected eight, have already appeared. Enquiries come from all over the world and he has a unique collection of nearly 7,000 microscope slides, which is continually being increased.

Two special problems of gall midges are being particularly investigated. First the fluctuations in population numbers already referred to, and secondly the host plant range of several injurious species, and particularly the Swede midge.

It is of the utmost importance for the agricultural entomologist to know the range of food plants of any pest. Dr. Barnes has recently shown that the Swede midge will breed on the wild yellow flowered water-cress and almost all the cultivated brassicas and raphanus.

The recent appointment of Miss Stokes has helped on with this work and she has shown that damage to *Sisymbrium*, Woad, *Lepidium* and Mustard, is probably produced by the Swede midge although previously attributed to other species of gall midges. The same midge can also make a variety of galls on flowers, inflorescences, fruits and leaves.

This work is being extended and similar work should be carried out in the tropics where there are a number of gall midges which eat scale insects, associated, for example, with die-back of cocoa and cloves. Their host range and distribution are very little known, although they may be important factors in the control of scales.

Slugs (H. F. Barnes and B. M. Stokes)

For some years Dr. Barnes had studied the slugs in his garden at Harpenden, working out their life history and examining methods of control. Recently—when he moved to Bedford—he carried on the work with particular reference to the Grey Field Slug which is the most widespread and common pest among the slugs, and the earthworm-eating slugs *Testacella*.

1,000 Grey Field Slugs were introduced into a slug-free garden and they have been under regular observation for a year, and the population changes here are being compared with those in a garden where the slugs are naturally established.

The *Testacella* slugs have a very tiny shell and this has made possible marking experiments. Marked *Testacella* have been recovered up to 580 days after marking. Miss Stokes is breeding the slugs in the laboratory and has already succeeded in getting eggs and young from two species of *Testacella*.

STAFF

The head of the Department, C. B. Williams, was invited by the French Government to take part in a small International Colloquium on " Ecology," in Paris, in Febrary, 1950.

BEE DEPARTMENT

By C. G. Butler

General

During 1950 the work of the department has proceeded along the lines which have been outlined in previous reports. Members of the department have continued to serve on various Committees and have taken part in a number of Short Courses for beekeepers. Two Extension Courses, arranged by London University and by Birmingham University, were conducted by Dr. C. G. Butler.

Mr. M. Hassanein, a temporary worker, returned to Egypt after obtaining his Ph.D. degree and Miss G. R. Wykes, after completing her thesis for this degree, has obtained a grant from the Agricultural Research Council to enable her to continue her work on nectar for a further year before she returns to Australia.

Miss M. Ryle and Miss E. Tyndale-Biscoe have joined the scientific staff and are extending the work on the relationship between nectar secretion and bee activity which was commenced by Miss Wykes.

The new building at Rothamsted Lodge, consisting of four small laboratories, workshop, honey-house and storage shed, was completed during the year. Besides relieving the congestion in the department considerably, it is providing greatly improved facilities both for research work and for the management of the bees. The home apiary and the old field laboratory and workshop have been vacated. As well as providing better facilities for our work this move has had the desirable result of bringing the apiary staff and the research staff together at Rothamsted Lodge.

Behaviour of the Honeybee in the Field

C. R. Ribbands has now completed his research on the effective flight range of the honeybee. This work was done by comparing the gains or losses in weight of stocks of bees sited right on crops with those of groups of stocks sited three-eighths and three-quarters of a mile away from the same crops. The principal crops on which this work was done were apple, lime and heather, and on these crops experiments were carried out during 1949 and were repeated exactly during 1950. These, together with two additional experiments, produced data which showed that the effect of increasing the distance between the stocks of bees and the crops on which they worked was considerable and consistently detrimental to honey production, but that the magnitude of this effect varied considerably.

Colony net gains are the surplus left over after the requirements of the colony for immediate sustenance have been met. As these requirements are considerable and similar, irrespective of distance from the crop, the effect of distance upon colony net gains is much greater than its effect upon the quantity of forage brought into the hive. Similarly, the effect of distance upon honey yield to the beekeeper is even greater than its effect upon colony net gains, because a large and similar quantity of honey must be left to each colony for its use during the winter.

Some of the effects of the distance between the stocks and the crops that were observed could be attributed to increases in the length of time that it took the bees to fly between their hives and the crops, but most of them were mainly due to unfavourable weather conditions for bee activity in the field.

The results illustrate a disadvantage of the practice of placing a large number of colonies of bees in a single apiary. The results also suggest that when stocks of bees are placed in orchards for pollination purposes it may prove to be more satisfactory, under some conditions, to scatter them to the maximum extent that is convenient, rather than to place them in compact groups.

Ribbands has also demonstrated the fact that foraging honeybees are unable to communicate to other bees the colour or colours associated with a source of food that they have discovered. Butler has similarly shown that bees cannot inform other bees of patterns associated with sources of food. These results are in contradiction to the conclusions reached by J. Francon ("The Mind of the Bees," 1939, translated by H. Eltringham: Methuen, London), which were clearly based on unsatisfactory data.

Following on her exploratory field experiments carried out during 1949, Miss Wykes designed a series of laboratory experiments to determine whether honeybees exhibit any selective behaviour when offered equal volumes of solutions of the same concentration in any one experiment, but containing different constituent sugars. The results of these experiments show that the different sugars that were used are not all equally attractive to honeybees, as consistent preferences were exhibited for solutions of certain single or mixed sugars. These results are in complete agreement with those obtained in the field experiments of 1949.

It was found that the relative preference of the bees for certain sugars varies with different concentrations of the solutions. The preference exhibited by the bees in all experiments for solutions containing equal proportions of sucrose, glucose, and fructose, is unexpectedly high when considered in relation to the relative preferences shown by bees for other solutions of sugars. This result is probably of biological significance since nectar, the natural source of carbohydrate for the bee, usually consists of a mixture of sucrose, glucose, and fructose.

An investigation was carried out on the behaviour of honeybees, bumblebees and hover-flies when they were seeking food from sunflowers (Butler, Carlisle, Simpson and Tyndale-Biscoe), but the data obtained have not yet been fully analyzed.

Bee Breeding and Strain Trials

A further development in the technique of instrumental insemination of queen honeybees was made during 1950, and Butler (120) has described a new type of syringe tip which enables the syringe itself to be used as a probe. This new type of tip does away with the necessity of using a separate probe and when used in conjunction with a new type of diaphragm syringe that has been designed by Mr. R. Jarvis, of Rowlands Castle, Hants, obviates the need for a syringe holder. This new type of syringe can be held in the hand throughout the operation and is much easier to insert into the queen than previous types of syringe, thus reducing both the

length of time required for this operation and also the likelihood of damage being done to the queen. It is confidently anticipated that the use of this syringe will result in a higher percentage of successful results being obtained. Preliminary results have been very promising.

One of the problems connected with instrumental insemination is that in order to obtain results similar to those produced by natural mating it has been found to be necessary to inject into the paired oviducts of the queen six times as much semen as she receives in a natural mating. Attempts have been made by Simpson to study the fate of the excess spermatozoa but the work has been hampered by lack of sufficient queens. It is hoped to continue to study this problem during 1951.

An attempt was made by Simpson during 1950 to inseminate queen honeybees with semen taken from their own drone offspring. Since the drone honeybee is a haploid organism, deriving his genetic characters only from his mother, this procedure would be equivalent to self-fertilization in plants and therefore very useful when attempting to breed pure strains of bees and also in genetical studies. The process is, however, somewhat tedious and involves stimulating the virgin queen to produce eggs by means of the carbon dioxide treatment (introduced by Mackensen (1940)), rearing the drones that are produced from these eggs and finally inseminating the queen with semen taken from them. This last stage in the process has so far not been completed on account of the difficulty of introducing semen into the paired oviduct because of the accumulation of eggs in the latter in a laying queen. It is possible, however, that this difficulty may be overcome by caging the queens for some time before attempting to inseminate them, or in some other way getting rid of any eggs that are occupying the lower parts of the oviducts.

During 1950 a number of queens were, as in previous seasons, successfully inseminated instrumentally by Simpson, Carlisle and Butler, and our breeding stock was maintained in a pure state in this way.

Attempts were also made during the summer of 1950 to obtain pure matings of three different strains of bees in mating apiaries in which only drones of the same strains as the queens being mated were maintained. Work is now in progress (Carlisle and Butler) in an attempt to distinguish those queens which have mated with the desired drones by studying the biometrics of their offspring and comparing these with the biometrical measurements of offspring of queens of these strains which have been instrumentally inseminated with semen taken from drones of the same strains.

Nectar Secretion

As mentioned earlier in this report experimental data have been obtained which suggest that honeybees have decided preferences for solutions of certain sugars in certain proportions. When these results were considered in relation to the occurrence of sugars in nectars and selection by bees of nectars in the field, it was found that few analyses of the constituent sugars in different nectar had been made, chiefly, no doubt, on account of the difficulty of obtaining large enough samples, and no useful conclusions could be reached.

Miss Wykes, therefore, decided to make a survey of the sugars which occur in samples of nectar from the flowers of a large number of species of plants, using the technique of paper partition chromatography for the analyses. Sucrose, glucose and fructose are the only major constituents of the nectars investigated, but maltose and two sugars of low RF values which appear to correspond to melibiose and raffinose respectively, occur in small proportions in certain nectars.

Preliminary work has also been done in connection with the quantitative determination of the individual nectar sugars separated on the chromatograms.

Feeding of Honeybee Colonies

J. Simpson has during 1949 and 1950 been investigating the composition of the stores of " honey " resulting from the autumn feeding of sugar syrup to colonies of bees. Analyses of the proportions of water and of sucrose have been made on samples of stores resulting from the feeding of strong (66 per cent sucrose) and weak (38 per cent sucrose) syrup. From the results so far available it appears that the water content of these samples are about normal but that the sucrose contents are, as indicated by other workers, much higher than in natural honeys.

C. G. Butler and Miss E. Carlisle continued the experiments carried out in previous years on the effectiveness of the feeding of various pollen supplements on the rate of build up of colony strength in the spring. It has been shown that the addition of a small quantity of yeast to soya-bean flour makes the latter much more efficient in this respect than soya-bean flour alone or soya-bean flour pollen mixtures. It appears that the yeast enables the bees to make better use of the soya-bean flour. It is hoped to continue this work during 1951.

C. R. Ribbands published during the year a paper on the autumn feeding of honeybee colonies (121) which indicates that it is more economical to feed concentrated sugar syrup (66 per cent sugar) than more dilute (38 per cent sugar) syrup.

Adult Bee Diseases

M. Hassanein, who has now returned to Egypt, continued his work on the influence of Nosema and Amoeba disease upon the behaviour of infected queen and worker honeybees.

It is hoped that it will soon be possible to appoint someone to work on bee paralysis and other adult bee diseases.

Brood Diseases

Mrs. Schreiner has now completed two years work on European Foul Brood. She has shown that Professor Burri's hypothesis that *Bacillus pluton* is a pathogenic form of *B. eurydice* is untenable.

During the course of this work she has developed a technique for testing the pathogenicity of various organisms concerned with European Foul Brood on the honeybee larvae and obtaining a definite result within forty-eight hours. She has at the same time attempted to culture *Bacillus pluton* in the laboratory, having previously shown that the media suggested by various workers for this

purpose are useless, and has obtained some important data which may result in the elaboration of a suitable medium for this purpose in the near futre.

Although it is virtually certain that *Bacillus pluton* is the organism that is responsible for the disease known as European Foul Brood this cannot definitely be proven until the organism has been cultured in the laboratory and innoculation tests have been made with pure cultures. It is also necessary to discover the life history of the causative organism before it will be possible to suggest rational methods of combating this disease.

Mrs. Schreiner is shortly leaving Britain to return home to South Africa. It is hoped that it will soon be possible to find a suitably qualified person to continue her work on this important subject.

INSECTICIDES AND FUNGICIDES DEPARTMENT

By C. Potter

The secondment of Mr. M. J. Way to Zanzibar to work on sudden death of cloves and the absence of Dr. A. H. McIntosh in the United States of America, and of Dr. K. A. Lord at Cambridge, has considerably upset the general programme of work of the department, although it is hoped that the department will ultimately benefit when they return.

During the year Mrs. Gillham resigned from the department and Miss C. M. Hutt was appointed in her place. Mr. J. Ward has been appointed as chemist to work on deposits of insecticides on plant surfaces. Miss Helen Salkeld of the Ontario Agricultural College has arrived to work in the department for two years, and Mr. R. W. Kerr, of the Commonwealth Council of Scientific and Industrial Research, Canberra, has arrived for a stay of one year.

During the course of the year Mr. T. D. Mukerjea was awarded the Ph.D. degree of London University and has now returned to India.

The work of the department during the year is set out below.

Chemical

Physical chemistry

(a) *The effect of particle size of suspensions of contact insecticides on their toxicity as contact poisons.*

Before his vist to Connecticut, Dr. McIntosh had shown that the contact toxicity of both rotenone and D.D.T. to adults of *Oryzaephilus surinamensis*, the saw-toothed grain beetle, and of D.D.T. to adult *Tribolium castaneum*, the flour beetle, was dependent on the size of the crystals of the poison in suspension. The relative toxicity of different sizes of D.D.T. crystal was shown to be dependent on the temperature of after-treatment. To explain these effects, Dr. McIntosh put forward a hypothesis based on the relative solubility of different poisons and of crystals of different sizes in the cuticular lipoids. He has continued to work at Connecticut using an injection technique to determine the differences in toxicity that occur when the insecticide does not have to penetrate the lipoid layer of the cuticle. The milkweed bug (*Oncopeltus fasciatus*) was used as test subject. When the insects were kept at 27°C. after treatment, crystals of both rotenone and D.D.T. were equitoxic with their colloidal material after two days, and afterwards the kills from the two types of suspension increased slowly and at the same rate.

If the insects were kept at 10°C. after treatment, colloidal rotenone was about 100 times as toxic as the crystals at the end of two days, but the ratio decreased with time and at the end of three weeks the total kill from the two types was about equal. When this comparison was made using D.D.T., which is more fat-soluble than rotenone, similar results were obtained; but the difference at the end of two days was approximately fifteen times instead of a hundred and the two types became equitoxic after about eight

days. When the experiment was carried out using the fluorine analogue of D.D.T. (D.F.D.T.), which is about five times more soluble in olive oil than D.D.T., there was no difference in toxicity at the end of two days or subsequently.

It appears that when suspensions of poisons of different crystal size are applied externally to the cuticle, differences both in speed of action and ultimate toxicity may occur. When these same poisons are injected, differences in speed of action can occur but the ultimate toxicity is the same. Dr. McIntosh considers these experiments provide further evidence of the importance of fat solubility and has prepared a paper in which the facts and their possible explanation are discussed in detail.

(b) *Effect of surface active agents on action of contact poisons.* Very little work on this subject has been done in the current year since it was discovered that with the technique in use, residual effects might obscure direct contact effects. Before continuing further therefore, an investigation of the technique was started and has not yet been completed.

Biochemical

Since Dr. Lord has been working at Cambridge during the current year, his study of the effect of insecticides on the oxygen uptake of insects has been left in abeyance, but it will be resumed on his return.

The study of insect esterase has been continued and the inhibiting action of the organo-phosphorus compounds on them has been studied, both Dr. Potter and Miss Hutt have taken part in this work. Various samples of T.E.P.P.-containing materials have been examined and a correlation between content of tetraethyl pyrophosphate, as determined chemically, and esterase inhibition has been established. This was also related, though less closely, to the insecticidal potency to adult *Tribolium castaneum* Hbst. of the various materials. A limited survey of the occurrence of insect tissues has been carried out and it has been shown, *inter alia*, that eggs of *Diataraxia oleracea* in an early stage of development (within 24 hours of oviposition) give this reaction and that it is inhibited by tetraethyl pyrophosphate-containing materials. This work affords some evidence that esterases other than choline esterase, may be important when considering the mechanisms of insecticidal action of the organo-phosphorus compounds. Since January, Dr. Lord has been working in the Sir William Dunn Institute of Biochemistry mainly on the purification and properties of the esterase obtained from the larvae of *Tenebrio molitor*. At the same time he has been studying techniques for the investigation of other enzyme systems, so that the scope of our investigations on the interaction between insecticides and insect enzymes may be widened.

Relationship between chemical constitution and insecticidal activity

Mr. Elliott has continued his work on the synthesis of compounds related to the pyrethrins.

Previous work provides evidence that pyrethrolone, cinerolone and the chrysanthemum mono- and dicarboxylic acids have very limited insecticidal action on their own. Further, esterification of

either keto-alcohol with other acids, or of chrysanthemum monocarboxylic acid with other alcohols not closely related to pyrethrolone or cinerolone, leads to compounds which do not have the rapid action and high toxicity of the pyrethrins themselves. These facts, amongst others, indicate that the high biological activity of these compounds is a function of the molecule as a whole; moreover, since tetrahydropyrethrin I and dihydro-cinerin I, whilst retaining some of the rapid paralytic action characteristic of these esters, are relatively non-toxic, the double bond(s) in the side chain are very important.

Two lines of work based on these considerations have been pursued.

(a) The synthesis of ketones related to the naturally occurring keto-alcohols in which a 3-methyl-*cyclo*pent-2-en-1-one derivative having an unsaturated side chain in the 2-position contains a group in the 4-position enabling it to be linked to (+)-*trans*-chrysanthemum monocarboxylic acid or to a compound derived from it. Such compounds would differ from synthetic compounds produced hitherto in their physical and chemical properties, whilst retaining a similarity to them in the relative positions in space of the chrysansumum acid residue and the unsaturated side chain.

$\gamma\gamma$-disubstituted-γ-lactones can by cyclized to *cyclo*pentenones in low yield by dehydrating agents. It has been shown in this work that β-carbethoxy-$\gamma\gamma$-disubstituted ethylenic acids and the corresponding lactones can be prepared in yields above 90 per cent by the modified Stobbe condensation of methyl *n*-alkyl and *n*-alkenyl ketones with diethyl succinate in the presence of potassium tertiary butoxide or of sodium hydride. The resulting half-esters can be cyclized by distillation from a slight excess of phosphorus pentoxide to 4-carbethoxy and 4-carboxy-*cyclo*pent-2-en-1-ones, which are characterized by their analysis, by their absorption in the ultra-violet region (λ max. 2350A), by their red 2 : 4-dinitrophenylhydrazones, and by their salts with aniline. A full description of this synthetic work and the reactions of these compounds will be published.

Investigations are in progress into possible methods of condensing these acids, or compounds derived from them, with chrysanthemum monocarboxylic acid, thus producing compounds in which the stereo-chemical configuration would closely resemble that of the naturally occuring keto-esters, which could be examined for biological activity. However, the *cyclo*pentenone ring in these compounds undergoes fission on treatment with dilute alkali or aqueous ammonia even in the cold, rendering the synthesis of such compounds difficult. Further study is being carried out on these compounds and on methods of esterifying the 4-carboxy-*cyclo* pentenones with alcohols closely related to chrysanthemum monocarboxylic acid.

(b) The investigation of the insecticidal activity of a range of synthetic esters related to the pyrethrins, very kindly donated at our request by Drs. LaForge and Schechter of the United States Department of Agriculture, Division of Entomology and Plant Quarantine, and by Dr. S. H. Harper of the Chemistry Department, King's College, London, in which the side chain of the keto-alcoholic component and the optical and geometrical isomeric forms

of the chrysanthemum monocarboxylic acid are varied. The work is being carried out by Mr. Elliott, Mr. Needham and Dr. Potter.

Preliminary results were described in the 1949 report, when the natural pyrethrins were compared with the (±)-allyl keto-alcohol esterified with the naturally occurring (+)-*trans* and synthetic (±)-*cis-trans* chrysanthemum monocarboxylic acids. This work has now been completed and published. The evidence obtained indicated that the ester with the (±)-*cis-trans* acid was generally approximately one half as toxic as that with the natural acid.

Further tests by contact spraying using the last stage instar larvae of *Plutella maculipennis*, using the ester of the allyl keto-alcohol with the natural acid and the ester with the (–)-*trans* acid have now shown that the latter has about 1/40 the toxicity of the former.

Results of contact spraying tests on adult *Phaedon cochleariae* and fully grown larvae of *Plutella maculipennis* comparing esters from mixtures of the geometrical and optical isomeric forms of chrysanthemum monocarboxylic acid with keto-alcohols with allyl and methallyl side chains indicate that there are not great differences in the insecticidal activity of the esters from the (±)-*cis-trans* form of the acid, and that the compounds with a methallyl side chain are only slightly less toxic than the corresponding esters with an allyl grouping. Of considerable importance is the fact that a compound with a but-3′-enyl side chain in which the double bond is shifted by one carbon atom further from the *cyclo*pentenone ring to the terminal position, has apparently an order of toxicity comparable to that of the ester with an allyl side chain.

In order to take into account specific differences in effect between the various compounds, work is in progress to extend the range of species used for the tests. Furthermore, to determine if any effects are due to differences in cuticular penetration, an attempt is being made to provide comparisons using an injection method, in addition to the usual contact techniques.

Biological

Bioassay

(a) *Tannin extract from Quebracho tree.* Quebracho timber is reported to be almost immume from insect attack. The Forestal Research Laboratories, Harpenden, kindly supplied us with a commericial extract used in the tanning industry which was tested for insecticidal properties.

The extract proved to be almost ineffective both as a stomach and as a contact poision to three species of lepidopterous larvae and three species of adult coleoptera. The test species were : *Diataraxia oleracea, Plutella maculipennis, Pieris brassicae, Phaedon cochleariae, Oryzaephilus surinamensis,* and *Tribolium castaneum.*

When injected into the haemocoel of final instar larvae of *Diataraxia oleracea* a dose of 0·2 mg. per individual of a 2 per cent aqueous solution of the extract produced 90 per cent mortality, but in view of the stomach and contact poison results no further work was done on the material.

(b) *Isothiocyanates.* These substances were thought to have some possibilities as insecticides and a quantity of a phenyl

isothiocyanate derivative was obtained from Roche Products Ltd., and tested.

Roche Products Ltd., has already found that the material was an effective anthelmintic.

The material was found to have some activity, but when tested as a contact poison was considerably less toxic than D.D.T., ranging from 1/64 as toxic with *Oryzaephilus surinamensis* L. adults as test subjects, to 1/8 as toxic with *Phaedon cochleariae* Fab., adults.

Following these tests it has been decided to examine the insecticidal activity of a series of related isothiocyanates which show considerable variation in their activity with nematodes as test subject, in an attempt to determine if similar changes occur with insects.

It is hoped that this work may give some information on the relationship between chemical constitution and insecticidal activity.

Bioassay techniques

A considerable amount of work has been carried out in the last year on techniques for the bioassay of insecticides.

(a) *Injection techniques.* Mr. Paul Needham has continued his studies on injection apparatus and technique.

A reservoir and tap have been fitted to the delivery arm of the micropipette injection apparatus described in last year's report, this makes refilling a more convenient operation.

Early tests using an extract of natural pyrethrins and *Locusta migratoria* L. and *Periplaneta americana* L., as test subjects, while giving probit regression lines that were not significantly heterogeneous, were not considered satisfactory since the scatter of the points was greater than was expected of this technique.

One reason for the wide scatter may have been the small number of insects that could be injected in one experiment when using the mechanical manipulator described in the 1949 report. This was due to the time taken to anaesthetise and secure the insect and position it accurately. Under these conditions only five insects would be injected at each concentration where a comparison of two poisons was required.

In later experiments the manipulator was dispensed with and the test insects held by hand. By this means the number of insects for any one test could be more than doubled and there was a marked improvement in the accuracy of comparison.

It is proposed to attempt to develop a better design of mechanical manipulator and to resume tests on the effect of precise manipulation of the test subject.

Some tests have been made on the suitability for injection experiments of the following insects—Adults : *Periplaneta americana* L (American cockroach) ; *Locusta migratoria migratoriodes* L. (African migratory locust) ; *Tenebrio molitor* (Meal worm) ; *Dysdercus fasciatus* (Cotton stainer) ; Larvae : *Diataraxia oleracea* L. (Tomato moth) ; *Pieris brassicae* L. (Large cabbage white butterfly).

L. migratoria and P. *americana* proved very suitable but require extra facilities in order to be reared in sufficient numbers to have enough individuals of a given age at any one time to obtain a comparison of two or more treatments.

D. fasciatus and *D. oleracea* appear, from the results so far obtained, to be most suitable test subjects. They have given the best probit regression lines and have the added advantage that they are easily reared in large numbers.

Some experiments have been carried out on the effect of the volume of liquid injected on the toxicity of the accompanying poison. Using *Diataraxia oleracea* L. larvae as test subject, an extract of the pyrethrins and allethrin as poisons, and a medium of 10 per cent v/v acetone, 0·1 per cent w/v sulphonated lorol in distilled water, it was found that the toxicity of the poison was affected by the amount of medium injected and that this effect varied with the mortality level. Thus for the pyrethrins, at L.D.75 the poison was twice as toxic when the same dose was injected in 0·02 c.c. of medium than in 0·01 c.c. while at L.D.25 the reverse held true. At L.D.50 there was no difference.

A similar result was obtained with allethrin but the ratios were obtained at different mortality levels. These experiments are to be continued.

(b) *Contact techniques.* Dr. Potter has continued to work on apparatus and technique for the examination of the effect of contact insecticides. There has been a continued interest in the laboratory apparatus for applying contact insecticides first described by Potter (1941) and it has now been installed in a number of laboratories both here and abroad. Requests have also been received for a description of the improved design and a considerable amount of time has been spent in the current year obtaining data on its performance.

The latest design has been shown to give a satisfactory distribution and replication of deposit with distilled water, a heavy petroleum oil and a light petroleum oil, this indicating that it is suitable for use with a wide variety of media. Electrostatic effects are now being studied.

Some further work on the relative importance of the direct contact effect and the residual film effect of poisons has been carried out and this is being continued.

(c) *Stomach poison technique.* Owing to Mr. Way's secondment to Zanzibar no further experimental work has been done on this subject, but a paper is in preparation for publication by Mr. Way on the relationship between insect body weight and resistance to insecticides, which includes data on the effect of stomach poisons.

The effect of stage of development on insect resistance

Mr. Mukerjea completed his study of the variation of resistance with the stage of development of the insect, using *Diataraxia oleracea* (Tomato moth), *Tenebrio molitor* (Meal worm) and *Periplaneta americana* (American cockroach) as test subjects and D.D.T. and Pyrethrum as insecticides. He has been awarded a Ph.D. of London University for this work which is now in preparation for publication.

The large differences in resistance that have been shown to occur throughout an insect's life history, clearly demonstrate the need both for accurate timing in the application of an insecticide and a detailed biological background.

Work on this subject is being continued by Miss Helen Salkeld who is studying the variation of resistance of insect eggs with their stage of development.

Factors affecting the toxicity and permanence of insecticidal deposits on plants

Work on this subject has been continued by Mr. Burt, and, towards the end of the year, by Mr. Ward. Experiments in 1949 on the toxicity of D.D.T. deposits on cabbage and turnip foliage showed, *inter alia*, that there was a fall in contact toxicity of the deposit over a period of two days immediately after spraying and that this was accompanied by an increase in stomach poison effect, thus indicating that the D.D.T. had not been removed from the leaf. The fall in toxicity could not be accounted for by dilution due to leaf growth and it was thought that it might be due to solution of the D.D.T. in leaf surface waxes. A study has therefore been made of the behaviour of D.D.T. on films of plant wax deposited on a glass surface.

Carnauba wax was first tried but no technique for preparation of an even film could be found and Sisal wax was then adopted, although it was not entirely suitable owing to its high melting point.

Some experiments showed that the thickness of the wax film on leaves varies with age. The maximum value found, $0 \cdot 5\mu$ for old cabbage leaves, was adopted as the standard.

A considerable amount of time was spent in developing a technique for the preparation of films of wax of known thickness; ultimately it was found that this could be achieved by dissolving the wax in warm toluene and spraying it through the Potter tower, and this procedure was adopted.

Wax films prepared in this way on plain glass plates were sprayed to give a known weight per unit area of D.D.T. crystals of needle form, average length 50μ. Some of the plates were subsequently kept at 65°F, and others at 110°F.

The temperature of 110°F. was included since preliminary experiments with thermocouples had shown that leaf temperatures of 18°F. higher than the air temperature could be reached in a glasshouse. The glasshouse temperature was 92°F. and thus 110°F. might be attained under field conditions. Experiments outdoors also showed that insolated leaf surfaces were above air temperature. With an air temperature of 75°F. the leaf temperature was 88°F.

It was found that the contact toxicity to adult *Tribolium castaneum* Hbst. of the D.D.T. deposits on wax was somewhat greater than on the plain glass surface, but this effect was overshadowed by the relatively rapid loss of toxicity of the D.D.T. both on the wax and glass surface when kept at 110°F. At 65°F. there was only a small loss of toxicity from both wax and plain glass surfaces over a period of three weeks; however, at 110°F. loss of toxicity was apparent after two days and after 14 days the L.D.50, determined from a range of concentrations, had approximately doubled, indicating a considerable loss of insecticide.

Weighing experiments using a micro-balance showed that the loss of toxicity was due to loss of D.D.T. from the surface and not to

solution in the wax. Between 60-100 per cent of the D.D.T. was lost in 21 days when the surface was kept at 110°F.

This loss was confirmed by analysis using the Schechter-Haller technique.

These experiments indicate that a comparatively rapid loss of toxicity of residual deposits of D.D.T. on foliage may occur due to volatility, at temperatures that can occur at leaf surfaces, particularly in warm climates.

None of the experiments however, showed the initial fall in contact toxicity found in the earlier experiments on cabbage leaves. It was thought that this might be due to differences in the constitution of sisal and cabbage leaf waxes and work is in progress to obtain some cabbage leaf wax and experiment with this material.

Mechanism of selection of strains of insect resistant to insecticides

Dr. Tattersfield carried out a series of experiments on selected strains of *Drosophila melanogaster* (the fruit fly). The progeny of survivors from insects treated with D.D.T. showed some evidence of increase in resistance over the untreated stock, but large variations in the resistance level of both treated and untreated stocks occurred throughout the series of tests and complicated the experiment. Examination of factors in the spraying and rearing technique that may be responsible for this variation is in progress in an attempt to determine whether the variation is inherent or not, and alternative methods of selection are under consideration.

Insect rearing

Eighteen species of plant feeding insects and nine species of stored products insects were reared during the current year.

Prodenia litura F. (the cotton worm), *Timarcha tenebricosa* F. (bloody nosed beetle), and *Dysdercus fasciatus* (cotton stainer) all plant feeding species have been added to the stocks during the current year. *Dysdercus fasciatus* and *Prodenia litura* have so far presented few difficulties for large scale rearing and the *D. fasciatus* is proving very useful for injection experiments. In view of the necessity for increasing the number of species of plant feeding beetles available as test subjects Miss P. Smith is working on the biology of *Timarcha tenebricosa* and has so far found that the diapause of the developed embryo in the eggs, can be broken by a period of refrigeration.

In view of their usefulness as test subjects further investigations have been made on the environmental factors affecting the biology of *Phaedon cochleariae* (mustard beetle), by Miss P. Smith and on *Diataraxia oleracea* (tomato moth) by Miss B. Hopkins.

A publication by Mr. Way, Miss Smith and Miss Hopkins embodying the work on rearing techniques up to date has been accepted for publication.

Insect diapause

Owing to the absence of Mr. Way only a little work has been done on this subject, but preliminary tests on *Pieris brassicae* (the large cabbage white butterfly) indicate that it reacts in a similar

manner to *Diataraxia oleracea* (tomato moth) since larvae reared at 65°F. with a 16-hour light exposure every 24 hours produce 100 per cent non-diapause pupae while those reared with a 9-hour light exposure gave 100 per cent diapause pupae.

Toxicity of plant protective chemicals to bees

Dr. Potter has continued to retain a supervisory interest in the work on the toxicity of plant protective chemicals to bees started by Mr. Glynne-Jones at Rothamsted in 1947 and now being carried on by him at the Seale Hayne Agricultural College.

Suitable testing equipment has been installed in the laboratory and the action of the organo-phosphorus compounds, Parathion, T.E.P.P. and Pestox III, have been examined when applied as stomach poisons, contact poisons and as residual films.

The M.L.D's of these substances applied as stomach poisons were: Parathion, 0·00004 mg./bee; T.E.P.P. 0·004 mg. (pure T.E.P.P.) /bee; Pestox III, 0·01 mg./bee.

The concentrations required to obtain an M.L.D. as a contact poison in aqueous medium were Parathon 0·0055 per cent w/v (deposit 0·00038 mg. Parathion/sq. cm.); T.E.P.P. 0·1108 per cent w/v (deposit 0·00012 mg. T.E.P.P./sq. cm.); Pestox III, $> 1·0$ per cent v/v (deposit 0·03 mg. Pestox III sq. cm.).

Parathion and T.E.P.P. proved highly toxic to bees when tested as residual poisons soon after application, but the toxicity fell off rapidly.

A 0·1 per cent v/v dilution in aqueous medium of both Parathion and T.E.P.P. applied to cabbage leaves gave 100 per cent mortality two hours after application following a minute exposure to the dry film. After 24 hours T.E.P.P. showed no toxicity and after 48 hours Parathion showed no toxicity. Parathion was not tested after 24 hours.

A 0·5 per cent v/v solution of Pestox III applied to cabbage leaves showed no toxic effects when tested 2 hours after application.

The work on factors affecting the toxicity of 3·4–dinitro–o–cresol, on the effect of inert dusts used as carriers of insecticides and on techniques for the evaluation of repellent chemicals is being continued.

For a number of reasons very little work was done on the natural fluctuation in the resistance of insect populations, the effect of host plant on resistance and the effect of environment on the toxicity of insecticides, but it is proposed to continue this work as soon as possible.

FIELD WORK

The experiment on the control of wireworms has been continued in collaboration with the Entomology and Statistics department, and the experiments on the control of insect vectors of potato viruses have been continued in collaboration with the Plant Pathology department. An experiment has been carried out on the control of *Aphis fabae* Scop. (bean aphis) on field beans.

Control of wireworms

The experiment started in 1947 has been continued to determine the long-term residual effects of the various treatments. Differences

showed on inspection during the growing season, and were obtained in the yield of wheat, although the differences were small. The following yield figures were obtained in terms of bushels/acre of wheat from the plots treated in 1947 and cropped with wheat since.

Untreated 15·5; B.H.C. (combine-drilled at 2·9 lb. crude B.H.C./acre) 15·0; B.H.C. (broadcast at 7·9 lb. crude B.H.C./acre) 16·1; B.H.C. seed dressing, 11·7; D.D.T. (7·2 lb. technical D.D.T./acre) 18·0; ethylene dibromide (45·5 lb./acre) 18·8; D.D. mixture (120 lb./acre) 16·9.

With the exception of the B.H.C. seed dressing, treated plots thus showed a slight improvement over the control, though the difference was only significant in the case of ethylene dibromide. The plots that had been sown with seed dressed with B.H.C. gave a yield significantly lower than that of the controls. In the second experiment in which B.H.C. was combine-drilled with the seed in 1947, the yield from the plots given the highest dosage (3·92 lb. crude B.H.C./acre) was significantly higher than the control plots.

Some further experiments were also carried out on the risk of tainting with the various B.H.C. treatments. The evidence obtained indicated that under the conditions of the experiment there was little risk of taint of crops grown in the third year after treatment. Dr. F. Raw of the Entomology Department carried out a survey of the wirewom population following the harvesting of the plots. The figures for the wireworm population of the plots showed good correlation with the figures for the yield.

A preliminary experiment on the effectiveness of aldrin and chlordane for the control of wireworms has been started.

Effect of insecticides on the population of Aphis fabae *Scop.* (bean aphis) *on field beans*

Aphis fabae Scop. is frequently a serious pest of field beans and some experiments were started to study the effect of various insecticides applied to control this pest. An attempt was made to determine both the immediate and subsequent effects of application of insecticides on the population of *Aphis fabae*, on its parasites and predators and on any other insects present. Yields were taken in the experimental plots.

Parathion, H.E.T.P., nicotine and D.D.T. were used on replicated large scale plots, two plots 198 ft. by 16 ft. of autumn sown beans and two plots 85 ft. by 16 ft. of spring-sown beans for each material. A set of preliminary trials were also made with a number of materials on small plots (42 ft. by 7 ft.) of spring-sown beans with no replication. The materials for this series were chlordane (technical) at 0·1 per cent w/v, allethrin (technical commercial sample) at 0·05 per cent w/v, pyrethrins at 0·05 per cent w/v total pyrethrins, toxaphene (technical) at 0·05 per cent w/v, aldrin (technical) at 0·1 per cent w/v, dieldrin (technical) at 0·1 per cent w/v, bis (bis-dimethyl-amino) phosphonus anhydrice (commercial technical sample) at 0·125 per cent w/v, D.D.T. and Wakefield half-white oil at 0·1 per cent w/v D.D.T. and 0·05 per cent w/v oil. The formulation was varied.

A single application was made of each material. The dates of application ranged from 10th–15th June, 1950. The table given below indicates the effect of the four insecticides used in the main

experiment on the aphid infestation on the spring-sown plots. There was a much lighter overall infestation on the autumn-sown plots.

Effect of insecticides on the population of Aphis fabae *Scop. (bean aphis) on field beans.*

Single application 12th–15th June, 1950

No. of aphid colonies on Spring-sown bean plots	*Parathion*	*H.E.T.P.*	*Nicotine*	*D.D.T.*	*Control*
10–15 days after treatment	34	105	105	2761	648
2 months after treatment	19	163	213	10240	1955

It appears that Parathion was the most effective material, and inspection showed that although aphid predators were also killed, the aphid population did not build up subsequently. H.E.T.P. and nicotine were also reasonably effective and they had a lower toxicity to the predators than Parathion. D.D.T. only killed in the order of 50 per cent of the aphids present, but was highly toxic to the predators and this is probably the reason why the final aphid population was markedly higher than on the control plots. The infestation was not heavy and there were very small differences in yield of seed from the treated and the control plots, except that the D.D.T. treated plots give appreciably lower yields.

Of the chemicals used in the preliminary tests allethrin, the pyrethrins, and dieldrin gave marked reduction of aphid infestation, the D.D.T. formulation again produced a higher population than the control.

It is proposed to continue these experiments.

Control of aphids carrying virus in potatoes

The experiments started in 1949 in collaboration with Dr. Broadbent of the Plant Pathology department, were continued in 1950. The 1949 results indicated that D.D.T., Parathion and Pestox III were preventing the spread of leaf roll but not virus Y. In 1950 the same insecticides were used again in an attempt to confirm this result and dieldrin and toxaphene were included to investigate their performance. It appeared that good control of the aphids was again obtained with D.D.T., Parathion and Pestox III. Dieldrin and toxaphene being less effective. The information on virus spread will not be available until 1951.

FIELD EXPERIMENTS SECTION

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments: E. M. Crowther (Chairman), H. V. Garner (Secretary), H. H. Mann, J. R. Moffatt, D. J. Watson and F. Yates.

The number of plots handled by the Field Staff at Rothamsted and Woburn were:

	Grain	Roots	Hay	Grazing	Total
Classical					
Rothamsted	115	72	50	—	237
Woburn	12	—	—	—	12
Modern Long-Term Experiments					
Rothamsted	279	264	160	64	767
Woburn	149	242	31	12	434
Annual Experiments					
Rothamsted	277	232	54	—	563
Woburn	—	40	—	—	40
Grand total ..	832	850	295	76	2,053

Note. Grain includes cereals, beans, peas, linseed. Roots includes potatoes, sugar beet, mangolds, cabbage, kale, leeks. Hay includes meadow and seeds hay, lucerne, cut grass.

The programme laid down for 1950 was successfully carried through with the exception of the classical barley plots at Woburn which had to be ploughed up owing to an exceptionally severe infestation of spurrey (*Spergula arvensis*). There was a serious attack of wheat bulb fly on the section of Broadbalk immediately following the fallow of 1949. This thinned the plant badly and a heavy infestation of corn buttercup (*Ranunculus arvensis*) occurred particularly on plots 9, 10 and plots that carried a poor plant of wheat. The Wheat after Fallow plots on Hoos field were also attacked by wheat bulb fly and were resown with spring wheat.

The characteristics of the season have been dealt with in the farm report. From the experimental point of view 1950 was a year of abundant growth of grass and fodder crops, heavy potato crops, and lodged cereals. Weeds grew fast and were difficult to control in crops such as beans and kale that could not be sprayed.

The classical and long-period experiments on both farms were continued with the exception of the 2-Course Rotation testing repeated dressings of agricultural salt which was terminated after the barley crop of 1950. Several of these experiments have been summarized in recent reports*. A few notes on the new ley arable rotation experiments at Rothamsted follow:

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* 4-Course Rotation. Residual effect of various straw manures. Summary of 14 seasons. Station Report 1946, p. 81.

3-Course Rotation. Effect of raw straw and straw composts. Summary of 14 seasons. Station Report 1947, p. 79.

6-Course Rotations, Rothamsted and Woburn. Effect of levels of nitrogen, phosphate and potash. Summary of 19 seasons. Station Report 1948, p. 90.

Ley Arable experiment, Woburn. Rotations with and without leys and legumes. Summary of 8 seasons. Station Report 1948, p. 94.

2-Course Rotation. Cumulative effect of salt on sugar beet and barley. Summary of 8 seasons. Station Report 1949, p. 101.

LEY ARABLE ROTATION

The second preliminary year of this experiment was very different from the first in regard to the produce of the plots under grass and forage crops. There was a very marked contrast in summer rainfall. In 1949 during the period April-September inclusive, there was only 8·0 inches, in 1950 over the same period 17·9 inches. The results for the two experimental fields were :

Production of dry matter, cwt. per acre, 1949, 1950

	Highfield		Fosters	
	1949	1950	1949	1950
1st year blocks :				
Permanent Grass	16·6	41·8	—	—
Reseeded Grass and Ley ..	23·3	35·6	14·7	35·3
Cut Grass	7·8	64·6	3·4	44·2
Lucerne	18·6	51·3	12·7	46·2
2nd year blocks :				
Permanent Grass..	—	49·4	—	—
Reseeded Grass and Ley ..	—	51·9	—	36·5
Cut Grass..	—	72·4	—	47·4
Lucerne	—	94·2	—	83·0

The level of production was much higher in 1950 than in 1949, cut grass in its first year, for example, gave about ten times as much in the wet summer than in the dry one. Lucerne was on the whole the biggest producer of dry matter, and the second year lucerne was much more productive than the first. In Highfield after old turf none of the grazing plots responded to extra nitrogen, but on Fosters on a poor arable soil there was evidence of nitrogen responses in first year grazing. In the wet season cut grass was very responsive to heavy nitrogenous treatment in both fields. One-year leys were poor in both fields and showed a response to extra nitrogen only on Fosters.

Test-crop wheat yielded 30 cwt. per acre in Highfield, and gave no response when the top dressing was increased from 2 to 4 cwt. " Nitrochalk " per acre. The yield was only 16 cwt. in Fosters, for there the plant wintered very badly. There was, however, a small nitrogen response on this field. Potatoes, the second-year test-crop, was excellent on both fields. The yield was 14 tons per acre for the basal dressing with no appreciable response on either field to dung or extra nitrogen. A further year's experience with sheep grazing on the grass plots showed that there are still improvements to be made in technique before the herbage is fully utilized by the animals. The wheeled hurdles used for the first time in 1950 were quite satisfactory.

THE ANNUAL EXPERIMENTS

Several of the annual experiments were carried out on behalf of various departments who will themselves report results. They were :

Eyespot experiment on wheat—Little Knott and Little Hoos : Dr. M. D. Glynne.

Wireworm experiment on wheat—Little Hoos : Dr. C. Potter.

Fertilizer Placement experiments : winter and spring beans—West Barnfield ; lucerne—Long Hoos ; kale—Stackyard ; old grass—Highfield : Dr. G. W. Cooke.

The remaining annual experiments were concerned with general fertilizer problems and were mostly the continuation of schemes begun in previous years.

Residuals in wheat of dung applied to potatoes

The main potato experiment testing various dung applications is usually followed up in a cereal crop to measure dung residues. The wheat of 1950, which received a top dressing of 2 cwt. sulphate of ammonia per acre promised well early in the season, but lodged in the wet summer; it yielded 27 cwt. grain per acre. The extent of the lodging followed the quantity of dung applied to potatoes the year before, the plots having 15 tons per acre were badly lodged and those receiving only 5 tons were standing. The differences in yield of grain due to residual dung were negligible, but there was more straw with the highest level of dung.

Dung applications to potatoes

This was a repetition of the 1949 experiment testing levels of dung and methods of applying it to potatoes and also the effect of the three standard nutrients. There was a heavy crop averaging nearly 14 tons per acre, with a big response to dung. The light dressing of only 5 tons per acre gave an increase of $2\frac{1}{2}$ tons of potatoes, the second 5 tons gave a further increase of $1\frac{1}{2}$ tons, but the heaviest application of 15 tons of dung gave no further improvement in 1950. The response to sulphate of ammonia was large and practically independent of the amount of dung applied. The potash response was over 4 tons in the absence of dung, 2 tons with light dunging, but negligible with the higher rates of application of dung. In 1950 the response to superphosphate increased with the amount of dung applied, thus in the absence of dung superphosphate gave a depression on yield, but in the presence of 15 tons of dung superphosphate gave a considerable increase in yield. Of these interactions with dung those involving nitrogen and potash have frequently been recorded before and are regarded as the normal behaviour. The positive dung-phosphate interaction, although statistically significant in this particular experiment, should be accepted with reserve, for usually dung slightly reduces the phosphate effect.

Methods of planting potatoes

An experiment which was begun in 1949 at Rothamsted to test methods of applying fertilizer when potatoes were planted by dropper, was repeated in 1950 at Rothamsted and Woburn. The following methods were compared with the ordinary method of hand planting in ridges:

(1) Broadcast fertilizer on the flat, ridge up, and plant in ridges with dropper.

(2) Broadcast fertilizer on the flat and plant on the flat with dropper.

(3) Ridge, apply fertilizer in ridges, split back ridges and plant in ridges with dropper.

A potato fertilizer was used at 8 and 16 cwt. per acre.

The first season, 1949, was exceedingly dry and the average yield was only 5·3 tons per acre. Even the single dressing of fertilizer had a barely significant effect and there was no further gain from the double dressing. The standard method of planting gave significantly less yield than the others, but this could not be attributed entirely to the effect of fertilizer location since it happened even in the absence of fertilizer.

In 1950 the Rothamsted experiment which received a basal dressing of 12 tons of dung per acre yielded no less than 15·1 tons without fertilizer. There was no improvement from a light dressing of fertilizer applied in the standard method, and the double dose of fertilizer was harmful no matter what system of planting and application was adopted. At both levels of fertilizer the standard method was inferior to all the dropper plantings. In both years at Rothamsted the dropper put in about 6 per cent more seed tubers than were planted by hand. This did not entirely account for the superiority of machine planting, but this point will be remedied in future experiments.

At Woburn where no dung was given fertilizer responses were extraordinary. The yield without fertilizer was 7·8 tons per acre. The first 8 cwt. of fertilizer raised the yield by 6·1 tons per acre and the additional 8 cwt. gave a further significant increase of 1·8 tons. At the lower level of fertilization the standard method gave much the same result as the others, but at the 16 cwt. level the standard method gave the smallest yield.

These experiments open up an important question and suggest that under certain conditions potatoes planted by dropper can make good use of broadcast fertilizer, and that the normal method of planting and manuring potatoes is not necessarily the most efficient under all circumstances. Further trials on these points are in progress.

Late nitrogenous top dressings for cereals

A start was made in 1950 to investigate the effect of very late nitrogenous top dressings on corn crops, applied when the plants were beginning to come into ear. It was claimed that in certain circumstances these dressings might increase both yield and nitrogen content of the grain. Three small preliminary trials were put down to test these points. The crops chosen had already received top dressings of sulphate of ammonia in spring: wheat, Squareheads Master, had $1\frac{3}{4}$ cwt. per acre; barley, Plumage Archer, $1\frac{1}{2}$ cwt. per acre; oats, Sun II, 2 cwt. per acre. The late top dressings of " Nitrochalk " were applied on June 27th and 28th. In the wet summer all the wheat was lodged and there was no obvious difference in the degree of lodging due to the late dressing. All the oats were lodged, and plots receiving extra nitrogen late in the season were flatter than the rest. All the barley plots were standing but those receiving the heavier dressings of " Nitrochalk," in June, were leaning but not lodged.

The yields are given below together with nitrogen determinations made by R. G. Warren :

"Nitrochalk"	Wheat		Barley		Oats	
cwt. per acre	Grain	Straw	Grain	Straw	Grain	Straw
			Yield, cwt. per acre			
0	24·5	49·0	22·7	28·2	31·4	53·9
1·5	25·9	51·3	22·7	29·6	30·0	54·1
3	25·5	50·6	23·1	29·5	28·8	53·0
S.E. ±	1·30	4·12	0·76	1·08	1·08	1·03
			Mean dry matter per cent			
	86·2	86·4	84·5	79·7	85·8	81·3
			Nitrogen per cent of dry matter			
0	2·38	0·54	1·55	0·84	2·37	0·49
1·5	2·46	0·58	1·81	0·95	2·50	0·72
3	2·58	0·70	2·03	1·11	2·64	0·87
			Increase in crude protein, cwt. per acre			
1·5	0·30	0·17	0·31	0·19	0·06	0·66
3	0·42	0·48	0·61	0·39	0·11	1·01
			Percentage uptake of added nitrogen			
1·5	20	12	22	13	4	45
3	14	18	21	13	4	35

In spite of a very favourable season for the action of late nitrogen there were no appeciable effects of late nitrogen on the yields of grain and straw.

There were, however, large effects on the nitrogen percentage or crude protein content for each crop. The crops responded in different ways. Wheat and barley both took up about one-third of the nitrogen added late whilst oats took up about one half. For each of the crops the heavy dressing of late nitrogen gave about one cwt. additional crude protein per acre. The additional nitrogen in the wheat and barley was distributed between the grain and the straw, the increase in the nitrogen percentage of the barley grain being relatively large since the barley without late nitrogen had a low percentage of nitrogen. In the oats nearly all the extra nitrogen was contained in the straw.

Where feeding barley or oat straw are fed on the farm, the use of very late top dressings of soluble nitrogen fertilizer may provide a useful method for obtaining additional crude proteins very cheaply. If further work confirms these results it will be necessary to devise machinery to apply these late dressings to corn crops with the minimum of damage.

Time of Planting Potatoes

In 1945 the Plant Pathology department began a field study of the influence of certain cultivation and manurial treatments on the spread of virus disease in potatoes, and the series of experiments devised for this purpose lasted for six seasons occupying a fresh site every year. The experiments have now terminated and the virus aspects will be reported by the Plant Pathology department. The agricultural treatments chosen, however, have considerable practical interest and are summarized here.

The standard form of the experiment consisted of four dates of planting spaced at intervals of about three weeks, each of these testing dung, nitrogen, phosphate, and potash in all combinations. There were consequently 64 treatments which were confounded into blocks of 16 without replication. This plan was followed in four years. In 1945 and 1947 certain of the factors were omitted so the main agricultural results of these two experiments will be recorded separately.

The sowing dates, which varied somewhat year by year according to the season may be classified as follows :—Early : end of March to early April ; Normal : third or last week April ; Late : second or third week May ; Very late : late May to early June. The actual dates in the four groupings do not overlap. The rates of fertilizer application per acre were : dung 15 tons at each date of planting, sulphate of ammonia 0·6 cwt. N, superphosphate 0·6 cwt. P_2O_5, muriate of potash 1·0 cwt. K_2O. Fertilizers were always put in the ridges shortly before planting, but dung was applied in this way only in 1946 and 1948, in the last two years the dung was ploughed in on all its appropriate plots before the first planting. The following table gives the planting dates and mean yields for each year, and the mean of these values over the four seasons. The main effects of dung and each of the fertilizers are recorded for each planting date, also the first order interactions of dung and fertilizers. Actual yields are given for the four combinations of dung and potash.

Time of planting potatoes, Rothamsted 1946-1950

	Dates of planting					*Mean*
1946	April 10	April 30	May 20	June 7		—
1948	April 10	April 24	May 8	May 22		—
1949	Mar. 29	April 20	May 10	May 30		—
1950	Mar. 31	April 21	May 11	May 31		—
Mean	April 4	April 24	May 12	May 30		—
	Mean yields : tons per acre					
					±	
1946	11·56	10·64	10·35	9·43	0·27	10·49
1948	12·15	9·22	9·42	6·91	0·50	9·42
1949	5·38	5·02	5·07	4·48	0·14	4·99
1950	12·14	11·00	10·55	9·18	0·36	10·72
Mean	10·31	8·97	8·85	7·50		8·90
Mean effects :						
Dung	3·35	2·81	2·40	1·92		2·62
Nitrogen	1·59	0·73	1·17	0·95		1·11
Phosphate	0·80	0·78	0·44	0·42		0·61
Potash	2·29	0·83	1·08	0·49		1·17
Interactions :						
Nitrogen × Dung ..	0·00	0·16	−0·06	−0·09		0·00
Phosphate × Dung	−0·38	0·27	−0·15	−0·64		−0·23
Potash × Dung ..	−0·70	−1·26	−1·58	−0·54		−1·02
Mean yields with :						
No Dung, No Potash	7·1	6·5	6·3	6·0		6·5
Dung, No Potash ..	11·2	10·6	10·3	8·5		10·1
No Dung, Potash ..	10·1	8·6	9·0	7·0		8·7
Dung, Potash ..	12·8	10·2	9·8	8·4		10·3

Yields were good except in the very dry deason of 1949. The yields, especially in well manured crops, fall off with delayed planting. Averaging over all manuring, potatoes planted near the beginning of April yielded over one ton per acre more than those planted towards the end of April or in the first half of May, but there was a large drop in the yield of potatoes planted at the end of May. The benefits from dung, nitrogen and potash were much greater for the earliest planting than for all later ones. The average gain from superphosphate was much smaller than from the other fertilizers and also varied considerably from year to year.

As in many other experiments the use of dung had no effect on the gain from nitrogen fertilizer, but the returns for phosphate and potash were much reduced on plots which had received dung. The interaction of potash with dung varied with the date of planting. This is illustrated by the mean yields at the foot of the table.

The gain from dung used without potash was about 4·0 tons per acre at each of the first three planting dates, but it fell to 2·5 tons at the fourth planting date. Dung and potash fertilizer together gave a marked improvement over dung alone at the first planting date but there was no gain from using potash as well as dung on any other planting date. The earliest planting allowed the crop to respond well to heavy manuring but potatoes planted later could make no use of additional potassium beyond that supplied in dung. On land receiving both dung and potash the earliest planting gave 4·4 tons of potatoes per acre more than the latest planting.

The 1945 experiment which fell out of line with the main series brought out an interesting point. Chitted and unchitted seed was planted at each of the four dates. The figures were :

Potatoes, tons per acre

	March 30	April 20	May 11	June 1	Mean
Ordinary seed	10·02	10·85	8·96	6·63	9·12
Chitted seed	10·27	10·90	10·11	7·99	9·82
Effect of chitting	0·25	0·05	1·15	1·36	0·70

There was the usual reduction in yield with delayed sowing, but the gain from using chitted seed was much greater on the later sowings than on the earlier ones. Chitting therefore slightly reduced the adverse effect of late planting. In this experiment the effect of dung and of nitrogen fell off rapidly with late planting, these effects being similar to those summarized above for the main series, but in a more pronounced degree.

In 1947, owing to the very late spring, only two plantings were possible, one on 5th May and the next on 24th May. There was only a small crop due to the very dry summer and all effects were small, but the results were in the general direction shown by the complete set of experiments.

Irrigation of Sugar Beet

The irrigation experiment of 1950 was carried out on the farm of Messrs. W. O. & P. O. Jolly, at Kesgrave, near Ipswich. It was a continuation of the experiment of the previous year on a somewhat larger scale, testing four levels of watering in combination with four levels of nitrogenous manuring :

On main plots :	*On sub-plots :*
O = No irrigation	0 = Basal manuring only (P, K, Salt)
A = Irrigation on farmer's system	1 = Basal + 0·4 cwt. N
B = Severely restricted irrigation	2 = Basal + 0·8 cwt. N
C = Restricted irrigation	3 = Basal + 1·2 cwt. N

The season will long be remembered for its showery summer which provided three inches more rain in the four summer months than the previous year. The figures recorded on the plots were :

	Inches per month				
	May	June	July	August	Total
1950	1·35	1·47	2·37	2·32	7·51
1949	1·99	0·42	0·72	1·54	4·67

The soil was a sandy gravel, the basal dressing 6 cwt. granular mixture providing 13·8 per cent P_2O_5, 13·8 per cent K_2O, and 4 cwt. agricultural salt per acre. Nitrogen treatments were applied as " Nitrochalk " before drilling. The seed was drilled on March 28th.

Watering began in mid-June and continued on certain plots until mid-September. The details were :

	Irrigation, inches			
		2A	2B	4C
June	13–16	—	1½	2
July	1–2	2	—	—
July	12	—	½	1
August ..	15	—	—	¼
September ..	13–14	—	—	¾
	Total	2	2	4

Since watering and nitrogen acted almost independently in 1950 the results are adequately brought out in the table below which gives the effect of water and of nitrogen separately for all attributes of the crop.

Mean yields with increasing levels of irrigation and with increasing quantities of nitrogen

Roots and tops tons per acre, sugar cwt. per acre, plant number thousands per acre, sugar per cent, noxious N mg per cent.

	Irrigation, inches				S.E.
	0	2A	2B	4C	±
Roots, tons	14.64	17.71	16.30	17.58	0.30
Tops, tons	6.42	6.92	6.88	7.13	0.20
Sugar, %	18.07	18.20	18.14	18.07	0.11
Sugar, cwt.	52.8	64.4	59.1	63.5	1.13
Plant No.	32.6	32.6	32.4	33.1	0.44
Noxious N., mg.% ..	32.8	30.0	31.6	23.8	3.94

	" Nitrochalk," cwt. per acre				S.E.
	0	2½	5	7½	±
Roots, tons	15.76	16.60	16.73	17.13	0.21
Tops, tons	5.74	6.44	7.35	7.81	0.15
Sugar, %	18.72	18.41	18.04	17.31	0.12
Sugar, cwt.	59.0	61.1	60.4	59.3	0.88
Plant No.	32.6	32.7	33.0	32.3	0.37
Noxious N., mg.% ..	20.2	25.4	32.4	40.1	1.84

There was an excellent crop with an average yield of 3 tons of sugar per acre. Every irrigation treatment produced a significant improvement over the dry plots. A single watering of 2 inches in early July (treatment A) gave an increase of no less than 11·6 cwt. of sugar per acre. Two inches applied, 1½ inches in mid-June and the remaining ½ inch in mid-July (treatment B), gave 6·3 cwt. sugar. While 4 inches of water, of which 2 inches were applied in mid-June and the remainder distributed from mid-July onwards (treatment C), gave 10·7 cwt. of sugar. The first method was significantly better than the second (+5·3 ±1·8 cwt. sugar). Whereas the effect of water has frequently been proved in these experiments this is the first occasion in this series where a substantial difference has been revealed between the irrigation treatments themselves. Since treatments A and C produced practically the same yields, and treatment B was intermediate, it appears probably that in this showery season where there was well distributed rainfall during July, August and September the outcome of irrigation treatments was largely decided by the amount of water applied on or before the first days of July.

The net effects of nitrogen on sugar production were small in 1950, the gains in root weights being largely offset by the reduction in sugar percentage. The tops and noxious nitrogen showed the usual increases.

THE FARMS

By J. R. Moffatt

The year under review brought no major change either in policy or direction of work, but will long be remembered because the execution of the work was made very difficult by the very wet summer and the atrocious weather during the corn harvest, which ruined what had promised to be a bumper one. The gradual relaxation of restrictions and controls, and the more plentiful supplies of farm necessities considerably eased the work of management, but the labour position gave cause for anxiety at certain times.

Field Experients

The number of experimental field plots in 1950 again showed an increase over the previous year, but despite the very unfavourable weather conditions during the summer and autumn, the full programme was carried through. The staff was just able to keep abreast of the ever-increasing number and complexity of plots with the aid of increased mechanisation and by working long hours of overtime.

The scarcity of seasonal workers will in the very near future limit the amount of experimental work which can be undertaken, as they are needed for the singling of the root crops, potato picking, and to help with the rush of work at harvest time.

Details of the field experiments are given in the report of the Field Plots Committee.

Cropping

The area farmed remained at 475 acres, with about 65 acres of woodland in addition. The main crops grown were wheat 104 acres, barley 36 acres, oats 10 acres, potatoes 35 acres, other root crops 20 acres, with smaller acreages of rye, linseed, beans, lucerne and vegetables, and bare fallow. The acreage under the various crops was very similar to previous years except that the area under wheat was increased at the expense of the barley. About 106 acres were under leys and 96 acres remained under permanent grass. This latter figure is gradually being reduced each year as it is ploughed up for experimental field plots.

Weather and Crops

The increased wheat acreage was sown by mid-November, 1949 under fairly good conditions. Two new French wheats, Nord Desprez and Petit Quin Quin, were tried and proved very successful in the very wet season.

The weather during December 1949 and early January 1950 was much warmer and drier than usual and land work was carried on without interruption. Ploughing, including a second ploughing of many of the fields, was completed by the middle of the month. Advantage was taken of a frosty spell later in January to apply and plough in farmyard manure for potatoes.

During February the rainfall was very heavy and land work was impossible. The land dried out in early March and good spring

seedbeds were obtained. Conditions remained good during April and May, and all crops were sown in good time in good tilths.

Haymaking started in early June in excellent weather, but the crops were rather light and cutting was delayed for a short while to enable more growth to take place. The crop from the early-cut fields was made in good condition, but with the deterioration in weather conditions the later cut crops were only made with difficulty, and the quality was poorer. A pick-up baler was used in 1950 for the first time. This reduced considerably the labour required to handle the crop, and freed labour for root singling. The whole hay crop was carted to the farmstead and stored under Dutch barns.

The wet weather in the latter half of June enabled all crops to make excellent growth, and at the end of the month harvest prospects were good. July, however, had a rainfall of more than twice the average and there were several very heavy storms. This, although encouraging the growth of root crops, also encouraged weeds, which became difficult to control, even in the root crops, under the continuous wet conditions. The corn crops suffered badly, many of them being severely laid and battered, from which they never recovered. The Nord Desprez and Petit Quin Quin remained standing and yielded exceptionally well.

Conditions for the corn harvest in August and September could hardly have been worse. Both months had rainfalls well above the average, spread over most days of the months. The laid crops and the bad weather made harvesting an extremely long and tedious operation which was not finished until early in October. The experimental corn crops were harvested early and in fairly good condition, but the preferential treatment afforded to these crops delayed the harvesting of the non-experimental crops. Further delay was caused by the fact that, having no means of drying corn, the small combine harvester could only be used to a very limited extent. Only about 30 acres were combined, but it is hoped by next harvest to have a sack drier. However losses were not as heavy as was at one time feared, despite the fact that one field had to be cut by mowers and carted loose. Losses from sprouted and shed grain were reduced by carting the corn as soon as it was fit, even though other corn still awaited cutting. By this system, during long spells of bad weather the crops were either under cover or still standing in the field. All the barley sold fetched the maximum price and the oats and much of the wheat was sold for seed. A small lot of wheat was found to be unfit for milling and will be used for stock feed.

The harvesting of the potato crop followed immediately after the corn harvest. The crop had made excellent growth during the wet season, although the plant was rather gappy as a result of the Scotch seed tubers being affected by Dry Rot. Weather conditions improved for lifting and as the ground dried out the speed of lifting increased but the work remained slow because of the heavy yield. The experimental plots were lifted by schoolchildren, and after considerable difficulty labour for the non-experimental areas was found at Bedford, and was transported each day to and from work. The lifting was completed just as the weather broke. On all areas yields were high, and the tubers were of good size and shape, with very little disease. The crop was stored under Dutch barns to a depth of 14 ft. to provide wet-day work for the staff during winter.

November again was a very wet month, with a rainfall of over twice the normal, spread over 24 days. The lifting of the mangold and sugar beet crops was seriously delayed, but fortunately the weather remained reasonably mild, and the mangolds suffered no harm. The yield of this crop, however, was disappointing. Conditions improved slightly in December, although a spell of hard frost prevented sugar beet lifting for about a week. However, this crop was all lifted by the end of the year. Yields and sugar content were satisfactory.

Pests and Diseases

The pest causing most damage in 1950 was undoubtedly Wheat Bulb Fly, a not unexpected occurrence in view of the hot, dry summer of 1949. The wheat on the section of Broadbalk field after fallow in 1949, and on the classical Half Acre strip after fallow was seriously damaged. On the former area weeds grew freely with little competition from the wheat, while the latter area was so badly damaged that it was redrilled late in spring with Fylgia wheat. Parts of some of the non-experimental fields where late-planted potatoes were grown in 1949 were also so severely damaged that they had to be ploughed up.

Late Blight attacked the potato crop earlier than ever before, but this was controlled until early September by spraying. The first spraying was done before the end of July, all areas being sprayed twice, and some three times. A low-volume sprayer fitted with large jets was used to apply the proprietary materials used, at about 60 gallons per acre under fairly high pressure. This worked very successfully. The haulm was burnt off about mid-September with sulphuric acid. These measures resulted in a crop almost free from blighted tubers. Several other materials were tested as possible substitutes for sulphuric acid, using both high and low volume machines, but acid proved by far the superior.

Fleabeetles caused very little trouble to the kale crop but spraying with a 15 per cent emulsion of D.D.T. was done as a precautionary measure. No damage was done to sugar beet or mangolds.

Aphids were far less prevalent than usual, caused little damage to the bean crop, and resulted in less virus yellows disease in sugar beet than usual.

Grassland and Livestock

The wet season made the grassland very productive and found us rather understocked with cattle to cope with the rapidly growing grass. Twenty-seven cattle were sold off fat from the grass and another four were sold at the local Christmas Fat Stock Show.

For the past few years Irish cattle have been purchased as stores, yarded in the winter to make farmyard manure, and fattened during the following summer. In future the policy will remain the same, except that Hereford-cross cattle will be used instead of the Irish Shorthorn type of cattle. The colour-marked cattle will present rather a less motley appearance than has been the case in the past. This autumn twenty-four Hereford-cross calves and thirty-four older cattle of the same cross were purchased.

The mixtures of grasses and clovers sown on the various experimental areas all took very well. The seeds sown in 1949, which were rather thin, thickened out well during the summer and gave excellent yields of hay, greencut grass, and pasture grass.

Sheep

The breeding flock of 151 ewes consisted in the main of sheep bred on the farm by mating an Oxford and Suffolk ram with Scotch Half-bred ewes. There are now very few of the original flock of Scotch Half-breds left. All the ewes were mated to Oxford rams for the production of fat lambs, but the lambing average of just over $1\frac{1}{4}$ lambs per ewe was lower than usual. The lambs did well in the early part of the season, but later a large proportion of them suffered from a severe attack by the sheep lung worm and several deaths occurred.

Each year now about half the lamb crop of the previous year is retained to provide animals for grazing experimental plots at Rothamsted and Woburn.

Labour

The labour position in 1950 was less satisfactory than last year. The number of permanent workers engaged was greater than in 1949, but the increase in the number of experimental plots, and the increasing complexity of the work upon them, many requiring operations throughout the summer, made extra demands upon the labour force. Extra work was also needed to keep weeds under control in the wet season. The labour available was about sufficient to meet normal demands, but was not sufficient to deal satisfactorily with root singling and potato lifting. Seasonal labour is needed for both these operations but is almost impossible to secure. There appears to be no alternative but to reduce the area of these crops.

Machinery

The implements and machinery on the farm have been kept up-to-date by replacing obsolete or badly worn items. A new tractor was purchased during the year, but the old one it replaced is being kept mainly for belt-pulley work. The only fresh equipment purchased was an engine-driven pick-up baler, which was used successfully for hay and combined straw, and a saw bench for cutting up home-grown timber.

Buildings

Early in the year a new open-fronted implement shed and farm workshop was completed, though this latter still has to be equipped. Plans are in hand for a general purpose building which will serve partly as a fertilizer and grain store, and partly as further storage accommodation for implements.

Estate Work

During the winter months maintenance work on the farm and estate was carried out, and part of the re-afforested area of Knott Wood was cleared of weeds and hazel coppice.

Local Show Successes.

At the local ploughing match the two horsemen secured two 1st and two 2nd prizes, and two tractor drivers received 2nd and 4th prizes.

At the local Christmas Fat Stock Show 1st and 3rd prizes were secured for fat cattle.

Woburn

The work at the Woburn Farm was directed and managed by the staff of the Rothamsted Farm, and though the farms are about 25 miles apart the system worked satisfactorily.

The number of field experiments carried out was again restricted by the shortage of permanent staff. A total of 498 experimental plots were laid out and drilled, but an extremely heavy infestation of spurrey necessitated the 12 plots of the Permanent Barley area being ploughed in during the summer. Of this total all except 40 plots were either classical experiments or modern long-term experiments.

The area farmed remained at 127 acres, of which 60 acres were under cereal crops, 33 acres under sugar beet or potatoes, 24 acres under grass and the remainder under experimental crops and fallow. The Woburn soil is well suited to the growth of potatoes and sugar beet, and the acreage devoted to these crops is as large as can be handled in a district where labour conditions are difficult.

The mechanization of field and farmstead operations and the re-equipping of the farm with modern implements, was carried a stage further during the year. New implements included a tractor-mounted hoe, a sugar beet topper and a tractor-mounted beet digger. After some initial difficulties these machines worked reasonably well until very bad weather conditions made it impossible to use them. The narrow row spacing (18 in.) increased the difficulties with the tractor-mounted machines, and a wider spacing of rows will be used in future. A reversible mounted plough was used during the year, making possible the cross-ploughing of the steeply sloping fields and eliminating the ridges and furrows on experimental and potential experimental areas. The mechanization of most of the operations on the farm enabled a very small permanent staff to carry through a somewhat larger programme of experimental work than in 1949, as well as a large area of labour-consuming crops, with less reliance on part-time workers. It is hoped to complete the mechanization in 1951 by the introduction of a small combine-harvester for non-experimental crops, and later to use a specially designed machine for harvesting experimental corn crops.

A much-needed new Dutch barn was erected at the farmstead during the year and this greatly increased the area of covered storage and working space. A range of open-fronted implement sheds and tractor garages was also erected which enables the implements to receive proper attention during storage. The one cottage let with the farm was modernized.

The facilities for the preparation and mixing of rations for livestock have been greatly improved by the provision of an automatic grinding mill, a food mixing machine and an electric pig food

boiler, This machinery will, it is hoped, reduce the time spent on the livestock, and enable better use to be made of home-grown feeding stuffs and unsaleable vegetables.

The weather during the winter of 1949-50 was generally mild, and rainfall was below normal in December and January. This enabled dung carting and ploughing to be carried out, and land work was well up to schedule by the time the weather broke towards the end of January. Conditions during March and early April were excellent for the preparation of spring seed beds, and spring corn crops were sown reasonably early. The planting of the sugar beet and potato crops followed immediately and although germination was rapid, subsequent growth was delayed by cold weather during May. This month saw the beginning of a very wet summer with a rainfall in the 6 months April-September of over 7 inches above the average. The farm was within the heavy storm area of 21st May when $1\frac{3}{4}$ inches of rain fell in under 3 hours. This caused quite severe erosion in fields not under grass or corn crops, and in some places gulleys were made over 3 feet wide and 4 inches deep. In some fields seed potato tubers were exposed by the washing away of the ridges, while on low-lying patches of sugar beet the plants of beet completely disappeared under silt and debris.

These conditions led to rapid growth of all crops but caused serious interference to all inter-row cultivations. Corn crops made too much straw, but looked very well until early July. Very heavy rains then caused much of the wheat and barley to lodge, and they never recovered, but fortunately very little lodging took place in the experimental corn crops. The lodged crops and the wet weather made conditions very difficult for the corn harvest but all the crops were eventually harvested in reasonable condition.

Potatoes made very rapid growth, especially during July and August, but the wet weather caused a very early and severe attack of Late Blight, which necessitated spraying. This was effective in retarding the spread of the disease but the haulm appeared to mature and turn yellow unexpectedly early in September. The tops were burnt off with sulphuric acid as soon as the ground could carry the equipment. Unfavourable weather delayed the start of lifting, but a dry spell in October enabled the crop to be lifted and carted under good conditions. The crop was stored to a depth of 12-14 feet in buildings at the farmstead to provide productive wet-day work. The estimated yield was approximately 12 tons per acre, with a high proportion of ware. The tubers were less damaged by cut-worm and less affected by scab than usual.

The wet season also favoured the sugar beet crop, which made rapid growth. There was far less virus yellows disease than in 1949, and bolters were negligible. Weeds grew rapidly and some difficulty was experienced in keeping them under control, especially as the ground had set so hard following the very heavy storm in May. The heavy crop (approx. 12 tons per acre) and bad harvesting conditions during the early winter considerably delayed the completion of lifting, but the work was accomplished by the regular farm staff.

The small areas of experimental market garden crops did well, though the red beet had far more bolters than usual, while the weather conditions made it impossible to keep on top of the weeds in the green pea crop. One area of January King cabbage suffered

severely from an attack by Club Root (*Plasmodiophora brassicae*) the fungus presumably being favoured by the wet soil conditions.

The appearance of the main experimental field (Stackyard) was greatly improved during the year by the felling of many dying trees and by the cutting and layering of the overgrown hedges.

Throughout the year the work of the Woburn Farm suffered owing to the shortage of farm workers. This is a result of the lack of cottages on the farm and the proximity of a large industrial concern. This shortage of permanent staff limits the amount of experimental work which can be undertaken and it is difficult to see how the position can improve unless houses become available to enable a suitable permanent staff to be engaged. Most of the seasonal work such as hoeing, singling and weeding, much of the haymaking and nearly all the planting out of experimental market garden crops was done in the evenings and at week-ends by casual workers. These are very unsatisfactory methods of working experimental plots.

The small herd of Large White pigs was maintained, and some fresh breeding stock was purchased during the year. The progeny were all carried on to bacon weight and were fed mainly on purchased feeding stuffs and brock potatoes. The new food-preparing machinery recently installed will, it is hoped, enable the pigs to be fattened very largely on home-produced foods. The very satisfactory maturity indices of the fat pigs were evidence of the satisfactory growth rate.

A small bunch of cattle were out-wintered, living mainly on sugar beet tops and straw. They were fattened on the grass in the early part of the summer. A larger bunch of Irish cattle was purchased in the late summer to consume beet tops and straw, and to make farmyard manure in the yards.

WOBURN EXPERIMENTAL STATION

By H. H. Mann

Season

The season of 1950 will be long remembered for its wetness, its high atmospheric humidity, and its apparant coldness. The rainfall was the highest on record, with one exception (1937) since 1925, and the humidity was substantially above the average for every month except March and October. There was a violent tornado on May 21st, when with a rainfall of nearly two inches within two hours, crops were drowned and silted up and soil was washed from one experimental plot to another. Most of these difficulties have been successfully met. The meteorological records from October 1949 to the end of 1950 are shown below.

Meteorological Records for 1949-50.

	Rainfall			Temperature			
	Total fall	No. of rainy days	Bright sunshine	Max.	Min.	1 ft. in ground	Grass Min.
1949	ins.		hours	F.	F.	F.	F.
October	5·02	15	129·2	60·3	45·4	53·5	40·2
November	2·66	18	74·9	48·7	36·9	42·4	32·6
December	1·20	16	57·8	47·1	37·2	40·9	32·4
1950							
January	0·65	10	34·6	43·5	33·8	39·9	30·3
February	3·68	18	59·1	48·0	35·9	40·3	31·3
March	0·69	12	135·6	53·2	36·7	43·9	31·1
April	1·96	18	156·5	53·3	37·9	46·4	33·8
May	4·61	13	155·2	59·2	43·2	52·8	39·6
June	1·58	6	269·7	71·5	51·6	64·9	46·7
July	5·34	17	193·8	68·7	52·7	63·5	49·6
August	2·59	18	183·1	68·8	52·0	62·2	48·6
September	3·10	22	122·3	62·1	48·9	56·2	46·6
October	0·50	6	105·0	55·5	42·3	49·9	38·6
November	4·27	22	60·2	47·4	36·6	42·8	33·7
December	1·40	16	36·5	37·0	28·5	35·8	27·1
Total or mean for 1950	30·37	178	1511·6	55·7	41·7	49·9	38·1

Field Experients

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that Committee will report separately on them. There are, however, a few points in connection with them that may be mentioned here.

Weed Studies : In 1947 it was necessary to fallow the permanent barley plots on account of a very severe infestation of wild oats. Very thorough fallowing has been continued ever since, and it is only in the fourth year that the land may be regarded as being free of wild oats, for during the growing season of 1950 practically no living plants could be found. It was observed that during the whole period the growing plants almost always originated in the top two or three inches of soil and rarely from deeply buried seeds. Periodical counts of seedlings during the course of the fallows were published in the last report.

This same area, and particularly the plots which had received many annual dressings of sulphate of ammonia, were also badly infested with spurrey (*Spergula arvensis*), and observations were made to see how far the fallowing had got rid of this weed. In 1950 however, it was found that spurrey appeared in almost as great quantity as at the beginning. Barley will again be sown on this area in 1951, and we shall be able to see how far the buried spurrey seeds have been able to survive over four years of careful fallowing.

Work has been carried out at Woburn on the relative effect of various weeds as competitors with barley. Three such annual weeds have now been studied, namely spurrey, mayweed (*Matricaria inodora*), and chickweed (*Stellaria media*), all of which are very common on the Woburn soil. Of these, it is found that a thick crop of barley can almost smother spurrey however thick the latter may be ; the smothering is not nearly so complete with mayweed though the weed is very largely reduced ; with chickweed, increasing the thickness of planting of the barley has very little effect on the vigour of the weed, which was able very largely to smother the barley. These weed studies have now been extended to the more general question of the influence of one plant on another. An account is being prepared for publication dealing with the mutual effect of barley and clover when sown together, under conditions made as favourable as possible for the barley.

The bolting of Beet Crops : In 1950 bolting of beet crops, which has been under observation at Woburn for a number of years, was very marked, particularly among red beet. As is shown in a publication now in the press any manure which causes more vigorous growth of sugar beet or red beet leads to an increase in bolting. Dung applied in the previous autumn slightly increased the number of sugar beet plants which went to seed, and when applied just before sowing it had a more marked effect. In all cases, sulphate of ammonia, and each of the organic manures, increased the amount of bolting of red beet, and a doubling of the amount of manure or the addition of sulphate of ammonia caused a further increase. Sewage sludge gave an abnormally large amount of bolting.

Exotic Crops : The possibilities of exotic crops on the well drained semi-acid soil at Woburn have been examined for many years. Among the crops tested are hybrid maize grown for grain, and soya beans of Swedish origin ; work was also done on serradella, birdsfoot trefoil grown for fodder, and sweet lupins for fodder or seed. The very wet season of 1950 had been a real test of the economic cultivation of several of these crops, particularly early hybrid maize and Swedish soya beans.

In spite of the very unsuitable season for maize, we harvested excellent crops of grain with several of the Wisconsin hybrids. The strain W.240 has now yielded well in all three years during which it has been grown, giving 27·5 cwt. per acre in 1948, 33·8 cwt. in 1949, and 36·6 cwt. in 1950, or a mean for the three years of 32·6 cwt. per acre. This seems the most promising type and it is now evident that it can flourish even in a most unfavourable year. The length of time between sowing and ripening which in 1950 amounted to 177 days is far longer than in the U.S.A. Another test will be made in 1951, and if this gives results as good as those hitherto

obtained, it would seem that suitable hybrid maize varieties can be confidently recommended, at least as smallholders' crops.

The story is very different with the varieties of soya beans which have been developed in Sweden and gave results of great promise in the dry warm summer of 1949. Soya beans are very sensitive to excess of water in the soil and when this occurs it is difficult to get properly nodulated roots even with inoculation. There has never before been any difficulty at Woburn in getting nodules on the roots of soya beans, even without inoculation, but in 1950, there was little or no nodule development, in spite of inoculating material supplied from Sweden. The result was that the plants grew badly and had an unhealthy appearance, and the excessive rain made the plots very patchy. The best of the varieties gave 10 cwt. beans per acre for a full plant, as compared with 14½ cwt. per acre in 1949. Further tests will be made in 1951.

Sweet Lupins : 1950 proved an excellent year for growth and the yellow variety (Weiko) yielded 16·5 tons per acre of green stuff on August 16th, equal to 2·57 tons of cured hay per acre. When spread for grazing animals in a field, the material was not at once relished, but all, except for a few stalks, had disappeared by the following morning. Sweet lupins, however, appear to be a rather uncertain crop, for after an excellent yield of fodder in 1948 (a wet year), the yield was only small in 1949 (a dry year). The production of seed was good in 1950.

Serradella : The yield of fodder was good amounting to 11·6 tons of green fodder on August 16th equal to 2·14 tons of hay, and was greedily consumed by grazing animals. This again is a crop which is much affected by the character of the season, for while in 1949 there was a good yield of seed and little fodder, in 1950 the production of good seed was very small while there was a fair amount of fodder. There is still much to learn, however, about how to deal with this crop during growth and harvest.

Birdsfoot Trefoil : The narrow leafed type, sown at the end of April, gave 3 tons of green fodder per acre on July 7th and, without any resowing, gave 18·4 tons of green fodder per acre on August 16th. This was readily taken by stock, and contained 16·8 per cent of dry matter, making the yield of hay equivalent as 3·64 tons in 1950. The wet season of 1950 seemed to suit the crop well, and the semi-acid soil at Woburn seemed to have no adverse effect.

Irrigation Experiments : During the year it has been decided to begin irrigation experiments at Woburn, under the general control of Dr. Penman of the Physics department at Rothamsted. Before selecting the site, the suitability of the soil and the water conditions of the land had to be tested and this involved a close investigation of the soil and subsoil of the area proposed for the experiment. A close examination of the subsoil conditions in this typical greensand area, was made to a depth of six feet, in a field which has been under arable cultivation as far back as records go. It is hoped that the experiments on the use of irrigation water with grass and other field crops will be started during the coming spring. The Station is indebted to the Woburn estate for the use of their private water supply for these irrigation experiments.

Pot Experiments

Clover sickness : The study of the failure of clover when it is frequently grown on the same land has been one of the investigations of the pot culture station for the last fourteen years. The failure here studied has not been connected with any parasite, though it often causes very great reduction of the yield of clover, particularly on soils more or less deficient in lime. As stated in last year's report we have discovered interesting facts about the sickness but have not yet found the actual cause.

We have found no other method of inducing the symptoms, except by repeatedly growing clover, but there is a definite correlation between the proportion of growing clover to soil, and the development of sickness. This has suggested the idea that the sickness is caused by a toxin which might be separated by washing the soil or sand in which the clover was growing and in 1950 we have given much time and work in attempting to do this, but without success. The washings from the soil on which a heavy crop of clover was growing had no injurious effect on clover plants. A similar negative result with the washings from sand cultures makes it unlikely that soil colloids retained the supposed toxin.

Another line followed up in 1950 was to see whether the burial of large amounts of clover roots or tops would have any effect in reducing the vigour of a crop grown after their burial. With roots no such effect occurs : with tops, using a very large amount of material, there did seem to be some reduction in growth of clover. These results though inconclusive, suggest that the clover tops when buried carry with them some toxin. This suggestion will be followed up. All antiseptics tried, including formalin, have failed to improve the capacity of a sick soil to grow clover.

The nutrition of crops under very acid conditions : The work on this question, which has been one of the main enquiries at the Woburn station for a number of years, has continued in 1950, but the results obtained are still under consideration. The principal point dealt with has been whether the actual amount of calcium present has any effect on the growth of barley, either in the presence of large amounts of soluble phosphates or otherwise. It is hoped to publish the results of this enquiry in the very near future.

Laboratory Work

The formation of nitrates in soil following various crop rotations : It is generally recognised that land which has been under a ley crop for several years tends to be more fertile than the same soil with similar manuring under a continuous arable rotation. The reasons for this are not fully understood and in an attempt to ascertain the cause Mr. Barnes has been studying the rapidity of the formation of nitrates in soils after each of the several treatments of the ley arable experiment, continued since 1938 in Stackyard field. On the whole, as a result of eight years of soil examination, he has found very little difference in the amount of nitrate formation taking place and so it would appear that the cause must be sought elsewhere. The results have just been published in the Journal of Agricultural Science.

Changes in the sulphur content of soils under long treatment with fertilisers and manures : At Woburn we have had land under barley for nearly eighty years, which has been treated with various manures every year for at least fifty years. Samples of the soils from each treatment have been taken from time to time, and these have afforded the opportunity to see how far the changes in fertility have corresponded with variations in sulphur in the soils. The work is now complete and is awaiting publication. It may be stated here, however, that there is little sign of any correlation between any form of sulphur in the soil and the yield of barley that was obtained. The accumulation of sulphur in the form of sulphate has been very small, and any increase which has taken place has occurred chiefly in the form of organic sulphur compounds.

SOIL SURVEY OF ENGLAND AND WALES

By A. Muir

The systematic surveys in Yorkshire, Lancashire and Somerset continued during the year and that in Somerset (Sheet 296, Glastonbury) is now completed. As a result of a request for a survey of the Fenland, a party has been established at Cambridge and has begun work on Sheet 188.

Lancashire

Sheet 75 (*Preston*)

The detailed field survey of the Preston district was continued and about 20,000 acres were mapped on the 6 in. to 1 mile scale. Surveying was largely concentrated in two areas, the first to the west of Chorley including parts of the parishes of Euxton, Ulnes Walton, Croston, Bretherton, Charnock Richard, Eccleston and Mawdesley, and the second to the north-east of Chorley, including parts of the parishes of Heapey, Withnell, Wheelton, Brindle, Whittle-le-Woods, Clayton-le-Woods and Leyland.

The first area consists of a gently undulating plain falling gradually to the alluvial flats of the Douglas in the west. In the east the soils are formed largely on till of mixed Carboniferous and Triassic origin and the dominant series are the Adlington and Gillibrand, while the Coppull series is of much smaller extent. These series have been described in the 1949 report. Further west, till of Triassic origin becomes the dominant parent material and the Cottam, Salop and Salwick series, described in the 1948 report, are the commonest. In the south-east of the parish of Charnock Richard, the till is locally of Carboniferous origin and the soils derived from it belong mainly to the Rothwell and Charnock series. Small patches of sand in the east give rise to soils of the Newport and Wem series whilst outcrops of Carboniferous sandstones and shales in the south-east and of Bunter sandstone in the south have led to the formation of soils of the Rivington and Bridgnorth series.

The second area consists of more strongly rolling country gradually falling away westwards from the moorlands bounding it on the east. It is largely covered by glacial deposits, but outcrops of Carboniferous sandstones and shales are increasingly common towards the east. Soils of the Rivington and Anglezarke series formed on the solid outcrops occur only very locally, and most of the soils are developed on morainic material and till. The very mixed, but

mainly light-textured, morainic deposits give rise to a haphazard distribution of Wem, Newport, Ellerbeck, Crannymoor and Chorley series, approximately in that order of extent. Till of Carboniferous origin to the east and of mixed Carboniferous-Triassic origin to the west, gives rise to a number of series, the dominant ones being the Rothwell and Charnock on the Carboniferous till and the Gillibrand and Adlington on the mixed till. A very approximate line of demarcation between these two groups is recognisable running north-east to south-west across the area.

Somerset

Sheet 296 (*Glastonbury*)

The survey of this sheet is now complete, and a soil map and report are in course of preparation. The work incorporates the results of an extensive revision of the older field maps, on which work was begun about 1934, carried out in the field during the earlier part of the year. The legend includes thirty soil series, and five complexes each composed of two or more series in close topographic association.

At the request of the National Agricultural Advisory Service, the Wiltshire County Council Farm Institute estate at Lackham, near Chippenham, was surveyed and a soil map prepared on the 6 in. to 1 mile scale. Eleven soil series were distinguished, including the previously described Sherborne, Badsey, Denchworth, and Bromham series. Five of the series are derived entirely from alluvium or terraces associated with the river Avon, and the remainder from solid formations or thin superficial deposits. The Kellaways Beds are well developed in this area, giving rise to deep brown loamy soils with a high base-status.

A survey of the Hampshire County Council Farm Institute at Sparsholt, near Winchester, was carried out on the 6 in. to 1 mile scale. The soil pattern appeared typical of the gently rolling chalk country of mid-Hampshire, where Clay-with-Flints is present, but rarely extensive or thick. The majority of the soils were grouped with the Andover, Wallop, Winchester, or Charity series which have already been recorded.

Yorkshire

Sheets 70 (*Leeds*) *and* 71 (*Selby*)

During the summer, mapping was continued on these two sheets and about 5,500 acres were mapped on the 6 in. to 1 mile scale covering their junction. The soil series found were the same as those mapped on these sheets during the previous season's work. This area included Stockbridge House Farm near Cawood in the East Riding which was surveyed at the request of the National Agricultural Advisory Service. It is situated on mixed drift deposits associated with the Escrick terminal moraine.

A further area of 5,100 acres was surveyed in the Wetherby district on the Leeds sheet on the 2½ in. to 1 mile scale, and a detailed survey of Headley Hall Farm, Bramham, was made on the 25 in. to 1 mile scale, at the request of Professor Comber of the Department of Agriculture, Leeds University. Both surveys include soils developed on Permian limestone and marl as well as on till and morainic material which occupy discontinous patches in the area. No new soil series were recorded and the soils could be grouped with those previously mapped on this sheet.

Cambridgeshire

Sheet 188 (*Cambridge*)

Detailed surveying on the 6 in. to 1 mile scale was commenced on this sheet during the year. Three surveyors were engaged on the work and a total of 36,000 acres was mapped. Surveying was concentrated in the south-east around Newmarket, but an area near Wicken and Soham was also mapped.

The south-eastern part is undulating and the underlying rocks are the beds of the Upper, Middle and Lower Chalk. However, they are extensively covered by boulder clay, old river gravels and their associated washes so that it is rare to find soils directly derived from the chalk.

Six series have been distinguished in this area, and of these the Wantage, occurring as a south-west to north-east strip at the edge of the Fenland, and the Hanslope, developed on the boulder clay in the sourth-east, have been described before. Of the new series two are tentatively considered to be red and brown calcareous soils. The Newmarket series occurs where thin washes from the river gravels overlie the chalk and the Swaffham Prior is developed from the chalk where it is mixed with some sandy drift. The Moulton series occupies a large part of the Middle Chalk and is found on the river gravel deposits and the associated washes. It is a freely drained soil which in some places may be non-calcareous but is elsewhere calcareous and may therefore be classified either as a brown forest soil or a red and brown calcareous soil. The Burwell series, like the Wantage, is a sedentary soil on the Grey Chalk and Chalk Marl, but as it occurs in low-lying areas, it is imperfectly drained.

The strip surveyed near Soham lies in the Fenlands and the parent materials of the soils consist of peats and alluvium with occasional river sands or gravels. Through this mantle the underlying Gault and Chalk Marl rise to form low ridges which are often overlaid with thin washes of sandier material.

In this area a further eight series have been distinguished, all of which are new. Seven of these are mineral soils and four of them, the Block, Newbarn, Peacock, and Bracks, are grey calcareous soils. The Soham series is a red and brown calcareous soil developed on mixed drifts overlying chalk while both the Wicken and the St. Lawrence are of rendzina type, the latter having a sandier parent material than the Wicken.

Where the peats and alluvium intermingle a very complex pattern of soils is formed and no series have been differentiated on them as yet, except for the Adventurers' series. This is an organic soil consisting of three feet of black amorphous peat.

Other Surveys

The mapping of experimental farms for the National Agricultural Advisory Service and University departments has continued and the Survey is collaborating with the Veterinary Laboratory at Weybridge in trying to correlate the incidence of Johnes disease with soil conditions.

SOME RESULTS OF THE SURVEY OF FERTILIZER PRACTICE, 1950

By B. M. Church

Introduction

Attention was focused on fertilizer policy in 1940 when it became clear then that not only would agricultural production in Great Britain have to be expanded as much as possible, but that every effort would have to be made to economize in the shipping space required for the import of fertilizers and feeding stuffs. In order to take decisions, for example, on the optimum proportion of shipping space to be allocated to fertilizers and to feeding stuffs it was necessary to know:

(a) the average responses of the different crops to different amounts of fertilizers, together with regional and other relevant differences in their responses,
(b) how farmers actually used the fertilizers available to them.

The amount of information readily available on these points at the time was slight. However the summarization of the results of fertilizer trials, undertaken by Crowther and Yates (1), provided valuable information on the responses of crops to fertilizers and enabled the priority of the needs of different crops to be laid down. At the same time more detailed and accurate information was required on how fertilizers were actually used, both for supply purposes and to see whether fertilizers were being used efficiently. It was with these objects that a Survey of Fertilizer Practice was carried out in 1942(2). The survey was a success from the start, and has been continued in various forms up to the present time. It provided valuable evidence in favour of continuation and increase in the supplies of fertilizers, made clear certain defects in the original over-simplified rationing scheme, and showed where farmers were failing to use their fertilizer supplies to best advantage. By 1946 information on fertilizer practice for the principal farming types throughout Great Britain was reasonably complete. However in 1948 a rapid survey was carried out in five districts to gauge the extent of the fertilizer shortage, which had been aggravated by the exceptionally early season, and to examine the effect of the shortage on fertilizer practice(3).

The 1950 Survey

During 1950 the survey was carried out in nine districts and it is planned to resurvey the same or similar areas in 1951 and possibly in 1952 so that changes in the use of fertilizers which may result from the reduction of subsidies and other factors may be examined. As in previous years the survey was carried out on behalf of the Provincial Advisory Chemists of the N.A.A.S. by members of their staffs in co-operation with the Statistical Department at Rothamsted.

In each of the districts chosen for survey the farms were grouped according to size (10-49, 50-149, 150-299 and 300 or more acres crops and grass). The farms to be surveyed were selected at random from within these groups, the sampling fractions being chosen so that the sample for a district included about ten or more

farms from each size group. This procedure was desirable to ensure that land on large farms was adequately represented and it increased the precision of sampling since fertilizer practice is known to be rather different on large and on small farms.

On every farm chosen for survey, details of fertilizer practice for the year 1949-50 were recorded for a random sample of the fields under each crop. When there were two or more fields under a crop two were examined, and records for a third field were taken when there were more than six fields. Acreages of all fields on the sampled farms were recorded and totals of these acreages were checked against 4th June returns. It was thus ensured that the results were not biased by the exclusion of outlying fields from the sample. Wherever the additional work of soil analyses could be undertaken soil samples were obtained for one tillage field, one of temporary grass and one of permanent grass selected at random from the surveyed fields on each farm.

Areas reasonably homogeneous for soil type and type of farming were surveyed and the districts were chosen so that the major farming types of the country were represented. Arable farming areas were represented by the districts of East Shropshire, South East Wiltshire and the eastern part of the West Riding of Yorkshire. Of the dairy farming areas South West Cheshire and North Dorset were surveyed, and information on other predominantly grassland areas was obtained from Northumberland ,North Buckinghamshire and Cardiganshire. It was proposed to survey the Isle of Ely and East Suffolk but unfortunately, due to acute shortage of staff, this was not possible and East Anglia is not represented. The survey was also carried out in Northamptonshire but results for this district are not available at the time of writing. A brief description of the surveyed districts is given in the appendix.

In this summary of the findings of the survey, comparison is made between fertilizer consumption in 1950 and in earlier years. The supply of farmyard manure and its distribution between crops, the use of fertilizers on grassland, and the use of nitrogen on cereals and root crops are also briefly discussed.

Fertilizer Consumption

Before discussing the use of fertilizers for individual crops and in the different districts of the 1950 survey it is of interest to see how the consumption for the whole country has increased in recent years. The figures in Table 1 show that the considerable increases in the use of all three components which took place between 1944 and 1948 have continued.

Table 1. *Consumption of fertilizers in the United Kingdom**

(thousand tons per annum for years ending June 30th)

	N	P_2O_5	K_2O
1939	60	170	75
1944	182	344	113
1947	164	355	108
1948	185	396	177
1949	184	418	196
1950	213	461	234

* Obtained from Monthly Digest of Statistics (4).

Between 1948 and 1950 nitrogen consumption increased by fifteen per cent, phosphate consumption by slightly more than this, while potash consumption increased by thirty per cent. Since there was a shortage of fertilizers in 1948 the rate of increase during the last two years may have been slightly less than is indicated by the table.

Fertilizer consumption is of course far from uniform throughout the country, varying with the soil type of the district and with the cropping. There are also considerable differences between districts of similar soil types in the manuring of individual crops. In Table 2 the fertilizer consumption per arable acre on arable land is shown for each of the districts surveyed. The use of fertilizers on the permanent grassland, which is excluded from this table, is briefly discussed in a later section of the report.

TABLE 2. *Use of farmyard manure and fertilizers on arable land*

(Overall rates F.Y.M. tons, N, P_2O_5 and K_2O cwt. per arable acre)

District	FYM	N	P_2O_5 Sol.	P_2O_5 Insol.	Total P_2O_5	Total K_2O
Mainly arable districts						
W. Riding	2·7	·29	·30	·08	·38	·32
Shropshire	2·4	·38	·36	·13	·49	·37
Wiltshire	0·6	·20	·31	·05	·36	·26
Mainly dairying districts						
Cheshire	4·6	·15	·18	·14	·32	·16
Dorset	2·1	·15	·20	·13	·33	·18
Other grassland districts						
Northumberland	2·0	·08	·14	·30	·44	·09
Buckingham	0·8	·09	·13	·16	·29	·07
Cardigan	1·5	·04	·08	·29	·37	·09

Nitrogen and potash are used more liberally in the arable farming districts, and the overall rates of application of potash are similar to those of nitrogen in most areas. Phosphate consumption varies much less from district to district and the variation is not so dependent upon farming type, thus the $N : P_2O_5 : K_2O$ ratio in arable districts is about 1 : 1.4 : 1 but in the poorer grassland districts it is approximately 1 : 4 : 1. As would be expected, the proportion of phosphate supplied as slag or in other less soluble forms, is greatest in the grassland areas. Of the arable districts in the sample Wiltshire naturally uses rather less fertilizers than the highly farmed areas of East Shropshire and the Vale of York where potatoes, sugar beet and other root crops are more important.

There has been no marked reduction in the regional differences in fertilizer practice in recent years since the increases in fertilizer consumption have been as great in the progressive arable areas which were already using more in 1945. The poorer grassland districts are using more fertilizers on their arable land than they were five years ago, and the proportionate increase in use of nitrogen and potash has been great since virtually none was used in 1945,

however the present rates of application in these districts are still very low. Comparative figures are given for Cardiganshire and for the Morpeth-Corbridge district of Northumberland :

		Application of fertilizers (cwt. per arable acre)		
		N	P_2O_5	K_2O
Cardigan ..	1945	·01	·35	·01
	1950	·04	·37	·09
Northumberland	1945	·02	·20	·01
	1950	·08	·44	·09

Changes in nitrogen and potash consumption in the dairy farming areas seem to have been rather greater and consumption of these nutrients was already appreciably higher in these areas in 1945. The figures for North Dorset may be compared with those from an earlier survey in the Honiton district of East Devon :

		Application of fertilizers (cwt. per arable acre)		
		N	P_2O_5	K_2O
East Devon	1945	·06	·37	·04
N. Dorset	1950	·15	·33	·18

Evidently phosphate consumption on arable land has hardly changed in the last five years in some of the grassland and dairying districts.

In the highly farmed arable districts, such as the West Riding and East Shropshire, fertilizers have been used generously for many years. In the West Riding increased consumption of nitrogen since 1948 has been largely on the temporary grassland while much more potash has been used on all the arable land :

		Application of fertilizers (cwt. per arable acre)		
		N	P_2O_5	K_2O
West Riding	1944	·24	·29	·20
	1948	·21	·30	·19
	1950	·29	·38	·32

The present level of consumption in the West Riding, particularly on the grassland, is below that of East Shropshire where the increase appears to have taken place earlier and the amounts of fertilizers used on the arable land changed little between 1948 and 1950 :

		Application of fertilizers (cwt. per arable acre)		
		N	P_2O_5	K_2O
East Shropshire	1944	·29	·41	·21
	1948	·38	·45	·30
	1950	·38	·49	·37

In addition to the large variation in fertilizer practice between districts, farmers in the same district differ greatly in their use of

fertilizers, and one aspect of this variation is shown in Table 3. The differences between the rates of fertilizers per arable acre on large farms and on farms of less than 150 acres crops and grass are given.

TABLE 3. *Differences between the amounts of F.Y.M. and of fertilizers used on arable land on farms of more than* 150 *acres and on smaller farms.*

(tons F.Y.M. and cwt. N, P_2O_5, K_2O per arable acre)

	F.Y.M.	N	P_2O_5	K_2O
W. Riding	—1·1	·12	·13	·14
Shropshire	—0·8	·10	·00	·10
Wiltshire	—0·3	·10	·08	·13
Cheshire	0·6	·00	·18	·04
Dorset	—2·4	·07	—·01	·19
Northumberland ..	—1·3	—·03	·17	—·04
Buckingham ..	—0·2	·06	·11	·06
Cardinganshire ..	—0·8	—·03	·12	—·07

In all districts except the dairying area of Cheshire where farmyard manure was freely available, more farmyard manure was used per arable acre on the small farms. These farms generally have a smaller proportion of tillage acreage and have more of their resources in dairying. The larger farms used more fertilizers per arable acre in all surveyed districts except Cardiganshire.

Such differences arise in part because in many districts heavily manured cash crops tend to be grown on the larger farms, however there is also a greater awareness of the value of fertilizers on the larger farms and they can more readily afford the necessary outlay.

A more detailed examination of the East Shropshire figures appears to indicate that since 1948 the difference between use of fertilizers on large and on small farms has decreased. Fertilizer consumption has been maintained on the larger farms while that on the smaller farms has increased. However, it should perhaps be pointed out that with samples of the size taken in the 1950 survey (about 40 farms in a district) apparent changes of this kind can only be regarded as suggestive as they may result from the inclusion of a few atypical farms.

FERTILIZER SUPPLIES

Supplies of fertilizers in 1950 were generally satisfactory with the exception of basic slag which was in short supply in most grassland districts. In Northumberland sufficient slag was available, but 25 per cent of the farmers stated that they had to take a lower grade than they ordered. In Cheshire, Buckinghamshire and Cardiganshire about a quarter of the farmers had difficulty in obtaining slag, one or two stating that they received as little as a third of their requirements. Others had to take lower grades or, as some preferred to do, go without supplies. There seems to have been a local shortage of potash in Cheshire where 15 per cent of the farmers might have used more had it been available. In most districts one or two farmers in the sample had difficulty in obtaining

nitrochalk, and this was particularly the case in East Shropshire, but supplies of nitrogenous fertilizers in general were sufficient to meet requirements.

Supply and Distribution of Farmyard Manure

The supply of farmyard manure in a district depends on the proportion of the land which is under grass, the level of stocking and the extent of the winter feeding of dairy cattle and bullocks. Thus in general supplies are more abundant in the north and west of the country but are somewhat restricted in the south-west owing to the length of the grazing season.

The table below shows the way in which farmyard manure is distributed between crops in the different districts, and the proportions of the crops which are dressed.

Table 4. *Supply and distribution of farmyard manure*

District	F.Y.M. available tons/acre	Percentage total supplies used on Cereals	Roots, other tillage	Leys	P.G.	Percentage of crop acreage dunged Cereals	Roots, other tillage	Leys	P.G.
W. Riding	2·2	2	95	2	1	1	54	3	1
Shropshire	1·9	10	81	5	4	6	60	4	3
Wiltshire	0·7	17	39	6	38	4	31	1	13
Cheshire	2·4	5	27	36	32	6	76	50	12
Dorset	1·1	5	25	20	50	5	41	21	9
Northumberland	1·2	7	52	18	23	3	37	9	4
Buckingham	0·5	25	38	22	15	6	28	6	2
Cardigan	1·0	8	62	23	7	3	54	6	2

It is known from previous surveys that in highly farmed arable districts such as East Shropshire, and in the greater part of the Eastern Counties, virtually all the farmyard manure is used on the arable land, most of it being applied to cash crops, potatoes and sugar beet, except in East Anglia where a large proportion of the cereal acreage is also dressed. Wiltshire is exceptional amongst the arable districts in that nearly half of the limited supply of farmyard manure goes on grassland and only about a third of the potatoes and other roots are dunged.

In the dairying and grassland districts however the use of much of the farmyard manure on grass is the general practice. An extreme example is North Dorset where almost three-quarters of the dung is used on grassland. Yet the survey has shown that in this district as in many other parts of south-west England the arable land gets relatively little farmyard manure. Thus in Dorset a quarter of the potatoes and half of the kale receive no farmyard manure, while the average rate of application to tillage was only 2 tons per acre in 1951. By contrast in Cheshire where supplies are plentiful, heavy dressings of farmyard manure are applied to most of the root crops and the kale.

The Use of Fertilizers on Grassland

The foregoing discussion on the use of fertilizers has been mainly undertaken in terms of the acreage of arable land. Until very recently the total fertilizer consumption of the country was largely determined by the amounts applied to tillage crops. Since the end of the war, however, and especially in the last two or three years the amount of fertilizer applied to grassland has shown a rapid increase. Whilst comparison with previous years is possible for only a few areas it is clear that the increases have not been by any means uniform over the country. The proportions of the grassland acreage which received fertilizers in 1950 are shown in Table 5 for some of the surveyed districts. Figures from earlier surveys are included for comparison.

Table 5. *Percentage of grassland receiving fertilizers*

		Temporary grass			Permanent grass		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
W. Riding	1944	9	13	0	3	3	0
	1948	14	17	1	11	16	2
	1950	31	42	18	12	25	5
Shropshire	1944	42	23	5	9	12	0
	1948	61	49	26	38	41	14
	1950	74	64	41	57	45	27
E. Devon	1945	7	24	2	1	11	2
Dorset	1950	58	54	25	18	16	5
Devon	1945	8	5	0	2	6	0
	1949	7	33	1	3	31	2
Cardigan	1945	3	25	2	3	17	2
	1950	11	31	9	4	2	2

It appears that in the main dairying districts (e.g. Cheshire and N. Dorset) and in the predominantly arable districts (E. Shropshire and the Vale of York) there have been considerable increases in the consumption of all three fertilizer components, on both leys and permanent grass. Thus in East Shropshire half the permanent grass received nitrogen and phosphate and one quarter received potash in 1950 against only a very small part of the acreage in 1944. Whilst similar comparisons cannot be made directly for the dairying counties, it is possible to use data for adjoining counties (N. Shropshire with S. W. Cheshire, E. Devon with N. Dorset) to show that increases of much the same general amount as in E. Shropshire have occurred for temporary and permanent grass in these districts also.

In the poorer grassland districts, as represented by Central Devon and the Morpeth-Corbridge district of Northumberland, there has been a very large increase in the use of phosphate (mainly as basic

slag) on grassland of all types, but amounts of nitrogen and potash applied, even on mowing fields, are still extremely small. Much the same features are shown by the data for an upland county like Cardiganshire, except that phosphate consumption has shown less tendency to increase, due in part perhaps to a shortage of basic slag in this part of Wales.

It will be realized that the figures quoted in Table 5 are averages over all fields of leys or permanent grass. In many districts, however, there are considerable differences between the manuring of grazed fields and of fields to be mown for hay. The proportions of hayed and grazed grassland receiving nutrients in 1950 are shown for two of the surveyed districts in Table 6.

TABLE 6. *Use of fertilizers on hayed and grazed grassland*

		Percentage of acreage receiving					
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
		Temporary Grass			Permanent Grass		
East Shropshire	For hay	88	56	45	19	9	0
	Grazed	68	75	42	59	47	31
Cheshire	For hay	59	65	38	47	46	19
	Grazed	33	78	39	44	58	33

These figures are not particularly well determined but it would appear that rather more nitrogen and rather less phosphate is used on leys for hay in these districts, the general levels of manuring on hayed and grazed leys being similar. It is remarkable that in East Shropshire the permanent grass for hay received much less fertilizers than the grazed fields. However of the permanent grass fields in this district nearly all those which were hayed were on the smaller farms which use fertilizers sparingly, while three-quarters of the grazed fields were on large farms. To a lesser extent this factor influences the other comparisons in the table.

The Use of Nitrogen on Cereals and on Root Crops

Previous surveys have shown that in districts where the level of fertilizer consumption is low very little nitrogen in particular has been used, and the more general use of nitrogen fertilizers in these districts would certainly lead to a valuable increase in agricultural production. As there has recently been some official concern that the use of nitrogen, particularly on cereals, might be no longer increasing, it is of special interest to examine the present use of this nutrient on cereals.

Trends in the last two or three years cannot be determined with any accuracy because of the districts surveyed in 1948 only two were surveyed in 1950. These two districts do not show a consistent trend. In the Vale of York the proportion of cereals receiving nitrogen appears to have increased by about 10 per cent, while the average rates of application have increased from ·23 to ·32 cwt. N. per acre. In East Shropshire it would appear that nitrogen was used on about 10 per cent less of the cereal acreage, and that the actual rates of application were also lower in 1950 than in 1948.

TABLE 7. *Percentage of acreage receiving and average actual rates of application of nitrogen to cereals*

District	Percentage of acreage receiving			Average actual rate cwt. per acre		
	1944	1948	1950	1944	1948	1950
West Riding ..	44	41	50	·21	·23	·32
Shropshire ..	36	56	45	·30	·37	·26
Wiltshire	75	—	78	·22	—	·25
C. Devon	19*	—	45†	·26*	—	·22†
Cardigan	2*	—	12	(·12)*	—	(·32)

* Figures for 1945.
† Figures for 1949.

As may be seen from Table 7 a considerable proportion of the cereal acreage of the West Riding and East Shropshire does not receive nitrogen. This is partly, but by no means entirely, due to the fact that in these districts cereals are often grown following a heavily manured root crop. Outside the arable districts nitrogen is still used on less than half the cereal acreage in most areas and the rates at which it is applied are low.

In general a rather greater proportion of the cereal acreage received nitrogen in 1950 than at the end of the war but except in the poorer grassland areas where consumption is still very low the increase during this period appears to have been fairly small.

The proportions of the acreages of the various root crops and of kale which received nitrogen in 1950 and the average rates of application are given in Table 8. Except in one or two districts where arable farming is of relatively minor importance, for example Dorset and Cardiganshire, nearly all the potato acreage received nitrogen and the average actual rates of application were reasonably high at about 0·8–1·0 cwt. N. per acre. However the rates at which nitrogen was applied varied greatly within districts, and some of the potato fields received very light dressings. In Cardiganshire less than half the potatoes received nitrogen and the rates of application were low.

In the only two districts where an appreciable acreage of sugar beet was grown the crop was treated very similarly to the potatoes.

TABLE 8. *The use of nitrogen on root crops and kale*

(Percentage of acreage receiving and average actual rates of application, cwt. N/acre)

	Potatoes		Sugarbeet		Swedes and Turnips		Mangolds		Kale	
	%	cwt/ acre	%	cwt/ acre	%	cwt/ acre	%	cwt/ acre	%	cwt/ acre
W. Riding	96	·89	90	·93	73	·70	92	·67	58	·46
Shropshire	100	·90	99	·99	92	·54	99	·71	100	·66
Wiltshire	97	1·25	—	—	67	·47	73	·49	47	·47
Cheshire	87	·78	—	—	17	·54	66	·61	54	·40
Dorset	66	·70	—	—	—	—	60	·55	67	·29
Northumberland ..	82	·52	—	—	35	·31	70	·29	67	·29
Buckingham	100	·97	—	—	—	—	—	—	—	—
Cardigan	48	·27	—	—	—	—	40	·28	—	—

The manuring of the other root crops was less generally satisfactory, and only in East Shropshire did virtually all the root acreage receive nitrogen. Less than twenty per cent of the swedes and turnips in Cheshire and only 35 per cent of those in Northumberland received nitrogen, though the average rate at which it was applied was adequate. In most districts 30 per cent or more of the mangolds received no nitrogen fertilizer, and in the predominantly grassland areas the average dressings were no more than 0·3 cwt. N. per acre.

The manuring of kale is far from adequate in most counties. In most of the surveyed districts only half to two-thirds of the kale received any nitrogen fertilizer. Although it is known from experiments that kale will respond to very heavy dressings of nitrogen the amounts applied on those fields receiving nitrogen were often small. Except in East Shropshire the average dressings in the surveyed districts were only 0·3–0·5 cwt. N. per acre.

REFERENCES

1. Crowther (E. M.) and Yates (F.). 1941. (Emp. J. Exp. Agr., **9**, 77.)
2. Yates (F.), Boyd (D. A.) and Mathison (I.). 1944. (J. Exp. Agr., **12**, 163.)
3. *Survey of Fertilizer Practice, results of rapid survey scheme* 1948. Duplicated Report.
4. *Monthly Digest of Statistics.* (H.M.S.O., 1950.)

APPENDIX

Districts covered by the Survey of Fertilizer Practice 1950

County	District	Number of farms surveyed
1. Northumberland	An area of mixed farming between Morpeth and Corbridge.	38
2. West Riding	Cash crop and dairying district of the part of the West Riding lying to the east of the line Ripon-Leeds-Sheffield (Vale of York).	49
3. Cheshire	The dairy farming area of south and west Cheshire, excluding the Peckforton and Bickerton Hills.	40
4. East Shropshire	The district of mainly arable farming with some dairying around Newport, Wellington, Shifnal and Bridgnorth.	45
5. North Buckinghamshire	That part of the dairying and mixed farming area of the county where the dominant soil type is Oxford Clay.	31
6. South East Wiltshire	Arable and dairying district based on the chalkland area of south and east Wiltshire.	49
7. North Dorset	Dairying district based mainly on heavy soils and consisting of the whole of Dorset north and west of the Chalk escarpment.	39
8. Cardiganshire	The whole of the county. Primarily an upland farming area.	40
9. Northamptonshire	The whole of the county. (This district is not dealt with in the report).	70

REVIEW OF WORK ON POTATO ROOT EELWORM

By B. G. Peters

Before summarizing the work of the Nematology department on this subject, a brief account of the nematode itself may be useful. The potato root eelworm, *Heterodera rostochiensis* Wollenweber, 1923, was first found causing damage to potatoes in 1913, simultaneously in Scotland (by Massee) and Germany (by Zimmermann), though there had been a doubtful report of it in Germany as early as 1881 (by Kühn). Its origin is quite unknown and there is no evidence to suggest that it came, with the potato, from South America. Today it is known as a serious parasite of only potatoes and tomatoes, and as mildly attacking a few solanaceous weeds. It was found in Yorkshire by 1917, and in Lincolnshire by 1924. Since then it has spread to most of the potato areas of Britain and Ireland. On the Continent it was early recorded from Denmark and Sweden, as well as Germany, and since 1940 has been found in Holland, Finland, France and Belgium. Outside Europe it is known only from Long Island. It thus appears to be limited to temperate regions, unlike the root-knot eelworm, *H. marioni*, which extends from the temperate zones throughout the tropics.

Like the other cyst-forming species of *Heterodera*, the potato root eelworm enters the finer roots of the growing plant in spring, as a slender larva about 0·5 mm. long. Entrance is assisted by the protrusible mouth-spear (present in all plant eelworms) and it is probable that histolytic enzymes are also involved. The larvae lie within the root cortex, some cells of which are destroyed. The head is closely applied to cells in the developing stele which become changed into giant cells. These in turn serve as sources of food, and the general result is to impede the free circulation of sap. The female worms swell considerably and, the head remaining within the root cortex, the sac-like body bursts out to the exterior some five to eight weeks after larval penetration. At this stage the worm-like males leave the root, fertilize the females, and are found no more. Most female nematodes lay their eggs as they are produced, but the potato root eelworm retains hers within the body, which swells until it is almost spherical, apart from the projecting neck and head. At first white, the colour of the female changes through yellow to brown, this being the outward sign of a chemical change in the nature of the cuticle, which becomes tanned to a tough leathery coating. At some indeterminate time the female releases her hold on the root cortex, falls off into the soil and dies. This stage, a tough, brown, inanimate, spherical sac containing living eggs, and measuring about 0·5 mm. in diameter, is the "cyst." Each egg is an oval, thin, chitinous membrane, about 100μ by 47μ, having a larva coiled within it when mature.

Cysts vary considerably in size. The largest, nearly 1 mm. in diameter, may contain upwards of 600 eggs. It is a feature of this and the other cyst-forming Heteroderas that eggs may remain alive within the cyst for many years—about 10 years but depending on conditions. Each year a few larvae hatch from their eggs and leave

the cyst, so that an old cyst may be almost or quite empty. The hatching and emergence of larvae is greatly stimulated by a chemical substance diffusing from the roots of growing potatoes or tomatoes. If a root is in the vicinity of a cyst, a large proportion of the contained larvae emerge from the cyst and enter the root, thus completing the life cycle.

A healthy potato may support many thousands of eelworms on its roots without obvious signs of distress. Usually, however, a heavily attacked plant is very stunted in growth. The foliage readily withers and turns brown and the tubers produced are both scanty and small, though not otherwise abnormal. In the field, an infestation first shows itself as one or more small patches of unthrifty plants, the patches extending with each potato crop. Eelworm disease makes itself felt, therefore, as a reduction in yield, especially of ware tubers. The position has been exacerbated in Britain by two world wars involving a great extension of areas under potatoes, with potatoes too frequently in the rotation. The annual economic loss in Britain has recently been officially estimated at £2 million, which makes this one of the worst of our potato pests. It is also a source of serious loss in tomato glasshouses.

The Nematology department came under Rothamsted's administration in 1947 and has been located at Rothamsted only since the summer of 1948. Before that it formed part of the now disbanded Institute of Agricultural Parasitology at St. Albans. In order to see the work on potato root eelworm in its correct perspective it will be essential to bring under brief review the earlier work at the Institute—work carried out successively by some who have never been on the Rothamsted staff: D. O. Morgan, Marjorie J. Triffitt, R. H. Hurst, Enid M. Smedley, and C. T. Calam.

The Institute's work started when Morgan investigated the Lincolnshire outbreak in 1924 and was joined a year later by Peters. After 1926 the biological problems were taken over successively by Triffitt, Franklin and Fenwick, Peters returning to them in 1945. Chemical aspects were dealt with by Hurst, Smedley and Calam.

Morphology and Systematics

At first all the cyst-forming species of *Heterodera* were regarded as biological strains of the one species *H. schachtii*, now the sugar beet eelworm. Misled partly by a German report that the potato root eelworm could slowly become adapted to living on beet, Triffitt (1928) concluded that Wollenweber's species, *H. rostochiensis*, could not be defended. She also found that the Lincolnshire strain produced smaller cysts when transferred to Hertfordshire clay. She noted that these cysts, and others from Ormskirk (1929b), were always of the round type, unlike the lemon-shaped cysts from most other hosts. Franklin (1939b) found that the latter bore minute superficial punctations, randomly scattered, whereas the potato strain resembled another round-cysted species (described from wheat in the United States of America) in having these punctations arranged in rows. Later (1940a) Franklin showed that at least some strains could be distinguished by measuring the lengths of larvae newly hatched or dissected from cysts. In the same year (1940b), on the basis of cyst char-

acters, lengths of males, length and digitation of spicules, and length of larvae, she split up the species *H. schachtii*, reinstating *H. rostochiensis* as the name of the potato root eelworm, and establishing two others. In addition, Fenwick and Franklin (1942) specified standard conditions for the measurement of larval lengths.

In 1935 Triffitt called attention to "microcysts," spherical bodies with a neck, found in soil, and closely resembling small cysts of the potato root eelworm. While the largest of these is larger than a small eelworm cyst, the smallest is actually smaller than an eelworm egg. If not empty, they contain an undifferentiated cytoplasm, and the wall is rigid and laminated. They are not of nematode origin, but no mycologist or zoologist will yet claim them.

Life-history and Biology

Triffitt (1930b) showed that the potato root eelworm tends to pass through only one generation in a year, although there would seem ample time for at least two during the potato's growing season. She found that cysts attached to potato roots did not turn brown until more than nine weeks after infestation in the spring. Later in the season some started browning before seven weeks, and by August all white cysts visible to the naked eye turned brown within 24 hours on exposure to the air. Eggs from white cysts were found to be immature.

Franklin (1938) showed that one-year-old cysts contained more eggs, and the hatching larvae invaded potato roots more rapidly, than was the case with older cysts. She had earlier shown (1937b) that hatched larvae survive in soil outdoors for 9 months, and in the laboratory for at least 16 months. Both these points have a bearing on the formerly frequent practice of growing potatoes year after year on the same land. The delayed hatching from older cysts might enable potatoes, in a rotation, to establish themselves before the invasion of their roots became heavy. In such a case the crop would be less likely to fail, though it might carry a large population of cysts later in the season.

In a pot experiment in 1925, Morgan had found potato eelworm cysts on tomato and *Solanum dulcamara* but none on sugar beet or mustard, or any other crop commonly grown in South Lincolnshire. Triffitt (1929c) could find none on ten solanaceous species tested. Franklin (1940a) carried out numerous infestation tests but, of cultivated crops, only tomato and potato were susceptible, and of other solanaceous species only *S. dulcamara*, *S. utile* and *Atropa belladonna*.

Triffitt showed (1930a) that oxygen was essential to the hatching of larvae in the laboratory. She and Hurst (1935) studied the thermal death point and found that the following exposures of cysts to hot water were lethal: 45 minutes at 116°F, 30 minutes at 120°F and 5 minutes at 130°F, shorter exposures at these temperatures retarded subsequent hatching. Exposures up to 1 hour at 110°F were without effect. Cyst contents are less susceptible to dry heat, judging from results found elsewhere.

In 1929b Triffitt reported feeding cysts to pigs. After passage through their alimentary canal the cysts were no longer viable, though it is unlikely that temperature is the lethal factor.

Root Diffusates

Early German work with the beet eelworm had shown that larvae were stimulated to hatch by a substance diffusing from the roots of the host plant. Morgan (1925) had failed to stimulate potato eelworms with diffusate from mustard (a host of the beet eelworm, then thought co-specific with the potato root eelworm) and had found that, when mustard was grown in the same pot as a potato, even the latter was only lightly infested. Triffitt (1930a) went thoroughly into this question, which has two main aspects: (a) the nature of the stimulating substance, and (b) the reason for the inhibitory effect of mustard. She found that the diffusate is produced only during the growing season but is not confined to the root tips. Though rapidly destroyed under non-sterile conditions, the substance is heat resistant, leachings retaining full activity after being reduced to half their volume by boiling. It remains active at high dilution (3 drops of leachings to 25 c.c. distilled water). The diffusate from mustard is present in shoots as well as roots, is less readily inactivated under non-sterile conditions, and has the effect of antagonizing the potato diffusate. This links up with later work by Smedley (1939) who found that sub-lethal dilutions of certain isothiocyanates delayed the onset of hatching. Triffitt also found that there is a dormancy period in winter during which larvae hatch very sparsely. In 1931 she showed that excess of diffusates did not check potato growth.

In 1932 Triffitt showed that root diffusates from certain grasses stimulated the hatching of potato root eelworm larvae, though these did not infest the grass roots. This was confirmed in a field experiment. In a later report (1934) she had good results from the meadow grasses (*Poa trivialis* and *P. pratensis*), moderate from rye grass (*Lolium perenne*) and slight from cocksfoot (*Dactylis glomerata*). Seven other grass species had no effect. This work was followed up by Franklin (1937a) who showed that white and yellow maize stimulated hatching; the effect was less than that of the *Poa* species, but maize is a more practicable field crop. She also found a slight response from *Alopecurus pratensis*.

The chemical nature of potato root diffusate is not only of theoretical interest: if known, it might point the way to effective control measures. Thus, if it could be cheaply synthesized, it might be applied to infested soil in the absence of a potato crop and so cause the larvae to hatch and then die of starvation; alternatively, the hatched larvae might be more vulnerable to attack by nematicides. The first step, concentration of the diffusate, was undertaken at the Institute by Hurst (1935, 1937) who produced an active powder by evaporation and ethanol precipitation of leachings from potted potatoes. In 1939 Calam, from Professor Raistrick's department, used leachings from potted tomatoes, adsorbed the active substance on charcoal, and then eluted it with aqueous acetone. The later, purely chemical work was done by Calam and others under Professor Todd, at Manchester, and latterly at Cambridge.

Pathogenicity

From the start there has been doubt as to how far the potato root eelworm was really implicated in the causation of "potato

sickness." Morgan (1926) was struck by the contrast between healthy-looking potatoes on the Kirton Institue farm, producing a reasonable crop, yet with their roots smothered in eelworm cysts and, on the other hand, poor diseased plants on neighbouring farms with relatively few cysts on the roots or even in the surrounding soil. The fungus *Rhizoctonia solani* was rife on these farms and he thought this might be a contributing factor. Triffitt (1929b) also found *Rhizoctonia* on potato-sick plots at Ormskirk, whereas both fungus and sickness were absent from another plot where eelworm was present. Nevertheless, *Rhizoctonia* was not always present on potato-sick land and, down to 1931 (Triffitt) and later, there is talk of some " unknown factor."

In 1929 Morgan and Peters found a positive correlation between cyst content of soil and pathological appearance of potatoes, classified as poor, fair and good, on a number of Lincolnshire farms. Series of soil samples were taken across typical potato-sick patches and in general the cyst count was highest near the centre of each patch. Attention was drawn to the fact that Morgan's (1926) healthy-but-infested potatoes grew on a farm where scientific manuring and crop rotation were practised. There now seems little doubt that potato sickness is primarily due to *Heterodera rostochiensis*. Where potatoes are poorly fed, relatively few cysts can lead to a crop failure ; where they are well cared for they may support a large eelworm population without obvious signs of disease.

Triffitt (1931) showed that, after an early set-back due to the eelworm, a healthy plant responds by forming new lateral roots. She found that such a plant maintains a normal transpiration rate. From a study of transverse and longitudinal root sections she showed that giant cells are formed and extend inwards towards the centre of the stele. In any one transverse section the area of vascular tissue might be reduced by one half, but longitudinal sections revealed that most vessels were plugged by the intrusion of giant cells, thus destroying the efficiency of the water-carrying system.

Soil Conditions

Morgan (1925) emphasized the importance of plant nutrients in soil in combating potato sickness. From a detailed study of a large potato field at the Kirton Institute, Peters (1926) found a negative correlation between soil pH and cyst content, later (1929) shown to be highly significant. There was no such correlation, however, in soil samples from several scattered fields in the locality (Morgan and Peters, 1929). Triffitt (1930a) drew attention to the effect of soil type, the heavier Hertfordshire clays giving not only fewer cysts, but also considerably *smaller* cysts ; she associated this with poor aeration in connection with hatching of the larvae. Experiments on the effects of soil type on an eelworm population are in progress at present.

Disinfestation of Tubers

One of the obvious ways in which cysts of the potato root eelworm can be spread is in the soil adhering to seed potatoes. Triffitt and Hurst (1935) sought to use hot water for disinfesting tubers, but the temperatures lethal to the eelworm (118°F for 30 minutes) were considered too high for the health of the tubers.

This was confirmed by Franklin (1939a) who tried also 5 per cent phenol, 0·2 per cent mercuric chloride, iodine (5 per cent of a N/10 solution in potassium iodide), and formalin. Phenol was lethal to the potatoes and mercuric chloride and iodine failed to kill the eelworms. Various formalin treatments, between 1 per cent and 5 per cent of commercial formaldehyde, were reasonably effective. In 1940b Franklin showed that the yield from Majestic tubers treated with 5 per cent formaldehyde in February was not affected, but tubers of Arran Pilot and Ally treated in December showed a 9 per cent loss. Fenwick (1942a) showed that sulphur dioxide was lethal to moist eelworm cysts and, while it killed chits already formed, treated tubers readily grew new chits ; he suggested that fumigation should be done prior to chitting. The rate was 1 and 2 sulphur candles per 860 cubic feet for 24 hours, in a thoroughly moist atmosphere.

Disinfestation of Soil

The work of members of the department in this field is reported in 16 published papers. Since none of the chemical agents used has been wholly satisfactory, it will be sufficient to summarize very briefly. Morgan (1925) tested a number of compounds and claimed a slight reduction in cysts on the roots from calcium cyanide and carbon disulphide, in pot tests. Hurst (with others) carried out numerous pot and field experiments mainly with calcium cyanamide and metallic oxides. Hurst and Triffitt (1935a) found nematicidal effects and increased potato yields from potassium ethyl xanthate and chinosol (both at economically prohibitive rates), and from ferrous sulphate, ferric chloride and ferric oxide ; the latter, which gave the best yield, was aimed at antagonizing the root diffusate. They then (1935b) tested sulphur, naphthalene, and a series of artificial fertilizers at high rates, calcium cyanamide being the only one with promise on a field scale. It was better than its probable break-down products (urea, ammonium salts, nitrates), but rates above 50 cwt. per acre were necessary to prevent eelworm multiplication. In 1937 Hurst and Triffitt reported on further small-scale tests with ferric oxide and calcium cyanamide ; both gave yield increases, but eelworm control was inferior to that in previous pot tests. In field trials, Hurst and Franklin (1937) got increased yields from calcium cyanamide at 30 cwt. per acre, sufficient to pay for the treatment and a reduced increase in eelworm population, but the ferric oxide results were negative. They used the same plots the following year, leaving the cyanamide plots untreated and treating the ferric oxide plots with cyanamide ; they found (Hurst and Franklin, 1938a) a yield response in the latter but no residual effect in the former. Field trials with various forms of ferric oxide, iron powder and zinc oxide gave disappointing results (Hurst and Franklin, 1938b), while a further cyanamide trial showed that cyanamide gave better yields than an equivalent of ammonium sulphate and lime, without killing all eelworms even at 40 cwt. per acre. Hurst (1938a) discussed the depth distribution in soil of cysts and of added cyanamide, showing that only in the top 4½ inches was there any kill of eelworm. He also showed (1938b) that acetic acid, in the form of pyroligneous acid, increased the killing power of cyanamide, and the latter was more effective in powdered than in

granular form. Throughout all these experiments Hurst was impressed with the difficulty of getting a sufficiently intimate mixture when solids are applied to soil.

Smedley (1936) showed that sodium hypochlorite solutions of 1 per cent available chlorine would dissolve eelworm cysts in half an hour ; they also dissolved larvae within the egg shell but not the shell itself which, however, was rapidly dissolved by calcium hypochlorite. The latter at 1 in 7,500 of available chlorine greatly increased the hatching of larvae. In 1938 Smedley showed that various chloro-acetates, and particularly the ammonium salt, were toxic to eelworms in soil, no larvae hatching from cysts treated at a rate corresponding to 15 cwt. per acre. In 1939 she reported on the good nematicidal effects of phenyl, ethyl, and n-butyl isothiocyanates. P–hydroxyphenyl isothiocyanate had no effect, and o– and p– tolyl isothiocyanates (like high dilutions of the first three) merely delayed hatching. The best was the phenyl compound, which was fully lethal to cyst contents as a vapour in 24 hours and also as a solution at 10 parts per million. Adsorbed on talc dust, it was used in a field trial at rates up to 2 cwt. per acre, giving increased yields and reduced eelworm multiplication. As before, the difficulty with field trials was the thorough incorporation of chemicals with soil.

During the last war, preliminary work was carried out on the dichloropropylene–dichloropropane mixture known as D–D. The results (unpublished) were sufficiently promising to justify a full-scale field trial under the auspices of the Agricultural Research Council. Seven 2-acre sites were used and many co-operated in the experiment, which was reported on by Peters and Fenwick (1949). Results were disappointing. At some sites (but not on fen soils) the highest rate of D-D used, 800 lb. per acre, gave a 50 per cent increase in yield and a 50 per cent kill of eelworm as measured four weeks after injection. After a following potato crop, however, the eelworm population was as high (or higher) on these plots as on untreated control plots. Peters (1948 a and b) has shown that D–D leads to an increase in yield of tubers even in the absence of eelworm, but that (1949) this effect is not carried over into a second year. The same pot experiment gave evidence that part of the food value of artificial fertilizers is diverted from production of tubers to production of eelworm cysts. Work on D–D and other nematicides continues.

Techniques

The establishing of various technical procedures should not go unnoticed. Morgan (1925) devised the method of recovering cysts from soil by flotation in water, Morgan and Peters (1929) showing that cyst counts from air-dried soil measured by weight were the least variable. Fenwick (1940) extended the method with an apparatus to take 200 gm. soil samples and another to take up to 1 cwt. : these are now in routine use. Triffitt (1929a) used a method for counting white cysts exposed on the roots of a potted plant when carefully turned out of its pot.

Fenwick (1943a) also devised a plate for isolating the progeny of 50 single eelworm cysts : individual receptacles were moulded from round coverslips. He has described methods for counting

eelworm larvae artificially "hatched" from cysts by the use of calcium hypochlorite solution (1942b), and stimulated to hatch by dilute picric acid (1943b). Latterly, Fenwick has dealt with the whole process of hatching in root diffusate. He has shown (1949) that the numbers of larvae hatching from individual cysts are so variable that it is desirable to use a batch of 100 cysts in any one test ; transformation of larval counts to a form suitable for statistical analysis is discussed here and in Peters (1948a). Later, Fenwick (1950a) has investigated the numbers of larvae hatching in successive time intervals : he has shown that a plot of the probit (corresponding to the percentage hatched) against log time is a straight line, both for single cysts and for batches of 100. Lastly, he has shown that, when potato diffusate is leached from potted plants into pots of infested soil, both the variety of potato and the type of infested soil (or of the contained cysts) have a significant effect on the proportion of larvae hatching. On the average 84 per cent of larvae hatched in the one season of the experiment. Surprisingly, about 50 per cent of larvae hatched in control pots receiving the leachings of pots in which no potato was growing, i.e. without the stimulus of root diffusate.

The Present Position

This review has necessarily dealt with published work, but it may be of interest to end with a brief account of current research on this pest. Inevitably, much of the past work has proceeded on an empirical basis which is effective only up to a certain point. Beyond this, fundamental work is required before progress can be made. The field trials with D–D mixture sponsored by the Agricultural Research Council are a case in point. The criteria were eelworm kill and crop yield at seven sites ; even where kill and yield were highest the subsequent increase in the eelworm population more than compensated for the initial kill. The discrepant results of these trials have largely influenced later work in the department.

Both kill and yield were very different at different sites, reflecting variations in soil type. There is here not only the persistent physico-mechanical problem of intimately incorporating chemicals in soils of differing structure, but also the many physico-chemical problems of the diffusion of a fumigant through soils and its sorption by clay particles or by organic matter. The department is not working on these but it is understood that the diffusion and sorption problems are receiving attention elsewhere.

Further, the ratio of eelworm kill to yield increase varied widely between sites. Taking yield as a rough measure of plant health, this situation involves the complex relationship between parasite and plant, and the factors making for disease, under the influence of a soil fumigant. It seems likely that the use of such a fumigant may lead to improved yields by directly killing eelworms, or by delaying the hatching of larvae so that the plant gets a good start, or by a partial sterilization of the soil independent of the presence of eelworm, or by some combination of these factors. Data which might throw light on this complex problem are scanty, and current pot tests with various fumigants always include a measure of the immediate kill, the response of subsequently grown potato plants,

and the final eelworm population. A co-operative 3-year field trial, with DD injections followed by potatoes each year, seems to show that this fumigant may improve the yield of the next crop without appreciably changing the final eelworm population. Laboratory tests, suggested by the Soil Microbiology Department, show that the nematicidal effects of frequently repeated soil injections with DD are cumulatively reduced, possibly due to the building up of a soil flora capable of splitting the molecules of the active ingredients The disease problem is also being explored by a histological study of plant roots under eelworm attack.

The mere assessment of kill in the D-D trials proved difficult. There is no direct way of finding what proportion of eelworm larvae within the cysts has been killed by a fumigant ; batches of 100 cysts are incubated in potato root diffusate until hatching ceases—a period varying up to 16 weeks. In a series of experiments since the trials Fenwick has investigated the conditions under which root diffusates act. As a result, not only can the hatching technique now be applied under optimal conditions but also a reasonable estimate of kill can be got in a matter of days rather than weeks, by following the early course of the hatch/time curve. Other results of this work include a method for the bio-assay of diffusates and evidence on their limited efficacy in soil : they are probably effective only in a narrow zone close to the root and (if production ceases) only for a few days, owing to their rapid breakdown in soil.

The recovery within a season of the eelworm populations on treated plots in the D-D trials has focussed attention on the rates of rise and fall of such populations. The annual rise is being followed in a pot test involving several edaphic factors, and the annual fall in crop-rotation field trials in co-operation with the National Agricultural Advisory Service at Cambridge. A highly dynamic concept of population is probably required to fit the facts. It is likely that most of the larvae hatch during one season from cysts lying close to a potato root, whereas some of those in more isolated cysts may remain quiescent for years. Even where annual determinations of larval density in soil show a fairly constant value, in the presence of potatoes each year, this situation probably conceals wide fluctuations within a season. The migration of larvae through soil, once they have hatched, is probably slight both vertically and horizontally ; the limiting effects of soil moisture and particle size on such migration are being examined in co-operation with the Physics Department.

Indirectly concerned with potato root eelworm, a rapid method for the preliminary screening of nematicides is being developed, using the free-living vinegar eelworm as a test organism. The ways in which nematicides act are largely unknown ; further work awaits fundamental studies in biochemistry and eelworm physiology.

Further progress in controlling potato root eelworm probably depends not so much on the efforts of isolated nematologists as of co-operative exploration of the frontiers with physics, chemis y, bio-chemistry and microbiology.

REFERENCES

1. Calam (C. T.), Raistrick (H.) and Todd (A. R.). 1949. Biochem. J., **45**, 513-519.
2. Calam (C. T.), Todd (A. R.), and Waring (W. S.). 1949. *ibid.*, **45**, 520-524.
3. Fenwick (D. W.). 1940. J. Helminth., **18**, 155-172.
4. — 1942a. *ibid.*, **20**, 41-50.
5. — 1942b. *ibid.*, **20**, 50-66.
6. — 1943a. *ibid.*, **21**, 37-41.
7. — 1943b. *ibid.*, **21**, 41-42.
8. — 1949. *ibid.*, **23**, 157-170.
9. — 1950a. *ibid.*, **24**, 75-86.
10. — 1950b. *ibid.*, **24**, 86-90.
11. Fenwick (D. W.), and Franklin (M. T.). 1942. *ibid.*, **20**, 67-114.
12. Franklin, (M. T.). 1937a. *ibid.*, **15**, 61-68.
13. — 1937b. *ibid.*, **15**, 69-74.
14. — 1938. *ibid.*, **16**, 67-76.
15. — 1939a. *ibid.*, **17**, 113-126.
16. — 1939b. *ibid.*, **17**, 127-134.
17. — 1940a. *ibid.*, **18**, 63-84.
18. — 1940b. *ibid.*, **18**, 85-88.
19. Hurst (R. H.). 1935. Agric. Res. Coun. Rep., 1933/5, 50.
20. — 1937. *ibid.*, 1935/7, 176.
21. — 1938a. J. Helminth., **16**, 57-60.
22. — 1938b. *ibid.*, **16**, 61-66.
23. Hurst, (R. H.), and Franklin, (M. T.). 1937. *ibid.*, **15**, 9-20.
24. — 1938a. *ibid.*, **16**, 1-4.
25. — 1938b. *ibid.*, **16**, 34-46.
26. Hurst (R. H.), and Triffitt (M. J.). 1935a. *ibid.*, **13**, 191-200.
27. — 1935b. *ibid.*, **13**, 201-218.
28. — 1937. *ibid.*, **15**, 1-8.
29. Morgan, (D. O.). 1925. *ibid.*, **3**, 185-192.
30. — 1926. *ibid.*, **4**, 49-52.
31. Morgan (D. O.), and Peters (B. G.). 1929. *ibid.*, **7**, 63-80.
32. Peters (B. G.). 1926. *ibid.*, **4**, 87-114.
33. — 1948a. *ibid.*, **22**, 117-127.
34. — 1948b. *ibid.*, **22**, 128-138.
35. — 1949. *ibid.*, **23**, 73-88.
36. Peters (B. G.), and Fenwick (D. W.). 1949. Ann. appl. Biol., **36**, 364-382.
37. Smedley (E. M.). 1936. J. Helminth., **14**, 11-20.
38. — 1938. *ibid.*, **16**, 177-180.
39. — 1939. *ibid.*, **17**, 31-38.
40. Triffitt (M. J.). 1928. *ibid.*, **6**, 39-50.
41. — 1929a. *ibid.*, **7**, 81-92.
42. — 1929b. *ibid.*, **7**, 93-98.
43. — 1929c. *ibid.*, **7**, 215-222.
44. — 1930a. *ibid.*, **8**, 19-48.
45. — 1930b. *ibid.*, **8**, 185-196.
46. — 1931. *ibid.*, **9**, 1-16.
47. — 1932. *ibid.*, **10**, 181-182.
48. — 1934. *ibid.*, **12**, 1-12.
49. — 1935. *ibid.*, **13**, 59-66.
50. Triffitt (M. J.), and Hurst (R. H.). 1935. *ibid.*, **13**, 219-222.

PUBLICATIONS

Physics Department

1. SCHOFIELD (R. K.). 1950. *Soil moisture and evaporation.* (Trans. Fourth Int. Cong. Soil Sci., **2**, 20-28.)

The evaporation (transpiration) from an area of land covered with active green vegetation cannot exceed a well defined maximum value which depends almost entirely on meteorological conditions, but may fall below this value if the water supply is inadequate. When the water supply is inadequate to maintain evaporation at this maximum rate, it is certainly inadequate to maintain maximum growth rate if other factors are favourable. Whether a water supply that is adequate for maximum evaporation will always give the greatest growth permitted by other limiting factors is not certain, but in recent experiments on the application of spray irrigation to sugar beet, substantial increases in yield were obtained by applying water calculated to be just sufficient to maintain maximum evaporation, but no further benefit was obtained from applying greater amounts of water.

2. PENMAN (H. L.) and SCHOFIELD (R. K.). 1950. *Some physical aspects of assimilation and transpiration.* (Proc. Conf. Soc. Exp. Biol. [In the press.]

Assimilation and transpiration can be treated as formally identical apart from a change in sign of the concentration gradient. The diffusive flow of carbon dioxide and water vapour is hindered by resistance arising partly outside the leaves and partly in the epidermis. Combination of the results of recent Rothamsted work on the physics of evaporation with a suggestion of Maskell's and some of the results of Brown and Escombe leads to a quantitative estimate of assimilation rates for indoor conditions which is of the right order. For outdoor conditions the length of daylight must be taken into account, and it is shown that the theoretical ratio of transpiration from turf to evaporation from open water agrees quite well with the value found experimentally. Extension to assimilation is attempted through evaluation of a " transpiration ratio "—normally a useless concept—for the limiting case when absorption is complete at the surface of the mesophyll tissue. It is shown that the very variable observed values of this ratio are many times the limiting theoretical ratio, i.e. that assimilation rates are never more than a very small fraction of what they could be. The discrepancy is attributed to the building up of relatively high carbon dioxide gas concentrations inside the leaf—almost reaching the normal atmospheric value—because the transfer of material in solution is much too slow to remove the absorbed carbon dioxide as fast as gaseous diffusion could supply it.

3. PENMAN (H. L.). 1950. *Recent Rothamsted studies in natural evaporation.* (Landbouwkundig Tijdschrift, **62**, 166-178.)

A survey of the energy balance method of estimating evaporation from weather data with applications to irrigation, field drainage, and river flow.

4. PENMAN (H. L.). 1950. *The diffusion of moisture through flax seed.* (British J. App. Phys., **1**, 213.)

A theoretical calculation confirming experimental value obtained elsewhere.

5. PENMAN (H. L.). 1950. *The water balance of the Stour catchment area.* (J. Inst. Water Eng., **4**, 457-469.)

The change in storage in a catchment area is the difference between rainfall and run-off, *minus* the evaporation loss. From measured values of rainfall and run-off, and from estimated values of evaporation based on weather data and an assumed nature of the vegetation in the area, it has been possible to estimate month-by-month changes in storage from 1933 to 1948. These changes show an annual cycle imposed on long-term trends and conform very well to the similar cycle and trends of observed movement of well-level. The treatment reveals that the month of minimum run-off is normally the last summer month in which evaporation exceeds rainfall ; that the storage is, on average, a minimum in September and a maximum in March, the level of a deep well lagging about two months behind ; that the average evaporation is very nearly constant at 20 in. per year ; and that the

estimate of this annual total is not greatly dependent upon the assumptions made about the distribution of vegetation in the catchment, although the monthly estimates will be so dependent.

6. PENMAN (H. L.). 1950. *Evaporation over the British Isles.* (Q. J. Roy. Met. Soc., **76**, 372-383.)

Theoretical value of average annual evaporation from the British Isles are calculated from long-term averages of air temperature, duration of sunshine, vapour pressure and wind speed for about a hundred stations. Direct estimates of the same quantity are obtained from long-term averages of annual rainfall and annual run-off from about forty catchment areas. The two kinds of estimate agree and are plotted on a map to show the geographical variation evaporation. This shows an increase from 14 inches per annum in Scotland to 20 inches along the south coast of England.

Chemistry Department

7. ARNOLD (P. W.). 1950. *The nature of precipitated calcium phosphates.* (Trans. Faraday Soc., **46**, 1061-1072.)

The absolute concentrations as well as the relative amounts of calcium and phosphorus determine the direction in which equilibrium conditions are approached in the CaO–P–P_2O_5–H_2O systems examined. A solid of atomic ratio Ca/P — 1·33 (octocalcium phosphate) was found to be the least basic of the apatite-like precipitates. It is probably a hydrated infinite two-dimensional complex with sheets held together by water molecules, $Ca_4H(PO_4)_3 \cdot 3H_2O$. Solids with atomic ratios Ca/P ranging from 1·0 to 1·33 consist of at least two phases: dicalcium phosphate and a solid at least as basic as octocalcium phosphate.

On structural grounds it appears possible that a continuous series of apatite-like solid solutions can exist between octocalcium phosphate and hydroxy- (or fluor-) apatite. In practice, no two preparations with composition lying between octocalcium phosphate and hydroxyapatite are likely to be identical.

The existence of precipitated calcium phosphates more basic than hydroxyapatite, the high loss of ignition of hydroxyapatites and the high fluorine contents of many natural sedimentary phosphates are explained on the hypothesis that thin sheets of apatite structure sorb hydroxyl or other anions where the calciums of the apatite lattice are exposed. Some evidence is obtained of complex ion formation in calcium phosphate solutions in which the atomic ratio Ca/P exceeds 0·5.

8. BREMNER (J. M.). 1950. *Amino-acids in soil.* (Nature, **165**, 367.)

Preliminary results of an examination of the amino-acid composition of soil hydrolysates by the paper chromatography technique.

9. BREMNER (J. M.). 1950. *The amino-acid composition of the protein material in soil.* (Biochem. J., **47**, 538-542.)

The amino-acid composition of acid hydrolysates of ten different soils has been studied by paper partition chromatography.

The following twenty amino-acids were found in every hydrolysate examined; phenylalanine, leucine, isoleucine, valine, alanine, glycine, threonine, serine, aspartic acid, glutamic acid, lysine, arginine, histidine, proline, hydroxyproline, αε-diaminopimelic acid, α-amino-n-butyric acid, β-alanine, γ-aminobutyric acid and tyrosine. Methionine sulphoxide and glucosamine were found in most of the hydrolysates.

Cystine, methionine and tryptophan could not be detected.

D-Amino-acids were detected in acid hydrolysates of soil, but the small amounts found could have arisen by racemisation during hydrolysis.

No free amino-acids could be detected in any of the soils studied.

The results indicate that the protein materials in different soils are similar in their amino-acid composition.

10. BREMNER (J. M.). 1951. *A review of recent work on soil organic matter. Part* 1. (J. Soil Sci., **2**, 67-82.)

A review of recent investigations on the uronic fraction of soil organic matter and the organic phosphorus and nitrogen of soils.

11. Cooke (G. W.). 1950. *Methods of applying fertilizer to potatoes planted by machines.* (J. Min. Agric., **56**, 571-3.)

The results of experiments comparing different methods of applying fertilizer for potatoes planted by hand in the furrows of ridged land are stated. The implications of these experiments for potatoes planted by machines are discussed. When machines are used to plant from flat land broadcast fertilizer must be applied before planting, a method which may make inefficient use of the fertilizer. Heavy dressings placed in the planting shoe may injure sprouting on light soils, on poor seedbeds and in dry seasons. The most efficient use of fertilizer should be obtained from machines planting on the flat if an attachment places the fertilizer beside and a little below the seed.

12. Cooke (G. W.). 1950. *Fertilizer placement and its application to horticultural crops.* (Worcs. Agric. Chron., **18**, 103-117.)

A general review of the advantage of placement and the results of experiments on arable crops. The applications of special methods of applying fertilizer to horticultural crops are discussed.

13. Deb (B. C.). 1950. *The estimation of free iron oxides in soils and clays and their removal.* (J. Soil Sc., **1**, 212-220.)

The results of the present study clearly demonstrate that no method is quite satisfactory for removing free iron oxides without affecting the crystal structure, but the hydrosulphite method has proved superior to other methods. Its merits may be summarised as follows:

1. Efficient removal of free oxides.
2. Less destructive effect on clay minerals.
3. Easy and quick manipulations.

The study of the base-exchange capacity as affected by different methods of extraction of iron oxides has thrown some light on the difference in stability of various clay minerals towards reducing agents. Thus:

1. Kaolinitic minerals are quite stable towards reducing agents.
2. Hydrous mica or illite is also fairly stable.
3. Montmorillonite containing iron is not stable towards the reducing agents.

14. Crowther (E. M.). 1949. *Soil fertility problems in tropical agriculture.* (Commonwealth Bureau of Soil Sci., Tech. Comm. No. 46, 134-142.)

A general review of current problems under the headings:
Soil fertility and crop production.
Dominant soil processes and nutrient cycles.
Soil organic matter and crop rotation.
Livestock and soil fertility.
Changing agricultural systems.
Fertilizers.

15. Crowther (E. M.). 1950. *Chemicals and crop growth.* (Advancement of Science, **7**, 37-38.)

16. Crowther (E. M.). 1949. *Soils and fertilizers.* (J. Roy Agric. Soc. **110**, 135-148.)

17. Crowther (E. M.). 1949. *Review of work on nutritional problems in forest nurseries.* (Rothamsted Report, 122-129.)

18. Crowther (E. M.). 1950. *The analysis of phosphate fertilizers.* (Chemistry and Industry, No. 48, 763-766); Summary 1949 (*ibid*, No. 27, 808-9).

The current Regulations under the Fertilizer and Feeding Stuffs Act, 1926, are quite inadequate for characterizing some of the newer kinds of fertilizer, many of which contain little or no water-soluble phosphorus but are good sources of available phosphorus in the soil. Some alternative methods of analysis are considered in relation to the complex equilibria involved in the decomposition of the calcium phosphates and to the agricultural value of various kinds of phosphate fertilizers.

119. Crowther (E. M.) and Garner (H. V.). 1950. *Nitrogen fertilizers for sugar beet.* (British Sugar Beet Review, **18**, 101-105.)

The relative values of ammonium sulphate and sodium nitrate for sugar beet were compared in 24 experiments on commercial farms in the years 1945 to 1948. Each nitrogen fertilizer was tested at two rates and on plots with salt and on other plots without salt. Normal dressings of phosphorus and potassium fertilizers were given on all plots.

The average gains in cwt. sugar per acre from ammonium sulphate and sodium nitrate were 6·2 and 10·2 on plots without salt and 7·0 and 7·9 on plots with salt. Where sufficient sodium is supplied from other sources sodium nitrate has only a small advantage over ammonium sulphate, but elsewhere sodium nitrate is far superior to ammonium sulphate because it supplies two important plant nutrients, nitrogen and sodium. Where sodium nitrate is used it is unnecessary to apply additional salt, but where ordinary compound fertilizers are to be used it is always desirable to apply about 3 cwt. of agricultural salt per acre at any convenient time during the winter or early spring.

20. Rickson (J. B.). 1950. *An improved micro-method for the determination of fluorine based on an examination of the fluoride-fluosilicate equilibrium.* (Analyst, **75**, 84-91.)

A study of the fluoride-fluosilicate equilibrium system indicates that low results in the micro-determination of fluorine by titrating with thorium nitrate, after separation of fluorine from interfering ions by distillation, may be caused by some of the fluorine being present as the fluosilicate ion SiF_6^{--}. The fluosilicate ion does not form an un-ionised compound with thorium as does fluoride.

Conditions for titrating fluorine with thorium nitrate so as to avoid this error are described, and the effects of chloride ions and varying pH on the method are discussed.

Pedology Department

21. Macewan (D. M. C.). 1950. *Solvation of clay minerals in relation to crystal structure : interlamellar adsorption by clay minerals.* (Trans. Fourth Int. Cong. Soil Sci., **1**, 107-109.)

A summarized history of the subject.

22. Stephen (I.) and Macewan (D. M. C.). 1950. *Swelling Chlorite.* (Geotechnique, **2**, 82-83.)

A note on the material mentioned in last year's report.

23. Talibudeen (O.). 1950. *Interlamellar adsorption of protein monolayers on montmorillonoid clays.* (Nature, **166**, 236.)

Evidence is presented to show the adsorption of polypeptide chains from three proteins in the interlamellar space of oriented flakes of nontmorillonoid clays. One-, two-, and four-layer complexes can thus be formed. The two-layer complex is inert to water and glycerol, and highly resistant to strong acid and alkali.

24. Talibudeen (O.). 1950. *Interlamellar adsorption in artificial layer structures.* (Clay Minerals Bulletin, No. **4**, 111-115.)

Conditions for the preparation of a zinc hydroxide with a layer structure are summarized ; it is shown that under controlled conditions, this adsorbs different amounts of anionic dyestuffs. At a critical concentration of the latter, these adsorption complexes adsorb non-ionized polar organic molecules in the manner of the montmorillonoid clays. Adsorbed dyestuffs are shown to be displaced by other dyestuffs quantitatively. An explanation for these properties is advanced on the basis of the preferential adsorption of zinc ions.

Soil Microbiology Department

25. Meiklejohn (Jane). 1950. *The pure culture isolation of* Nitrosomonas europaea. (Trans. Fourth Int. Cong. Soil Sci., **1**, 195-197.)

Nitrosomonas europaea (Winogradsky) has been obtained in pure culture from Rothamsted soil, by modification of Winogradsky's method, as follows :

(1) An enrichment culture was made and the population in it built up; (2) transfers were made on a new liquid medium; (3) the bacteria were removed from the carbonate particles with carbon dioxide; (4) colonies were picked from poured plates on silica gel.

26. Meiklejohn (Jane). 1951. *The effects of glucose on impure cultures of nitrifying bacteria.* (Plant and Soil.) [In the press.]
1. 0·02 M glucose sterilized by filtration delays nitrification.
2. Filtered glucose is not toxic to nitrifying bacteria, so the delay is presumably caused by the rapid growth of the non-nitrifying bacteria.
3. 0·02 M glucose autoclaved in the medium stops nitrification, and is toxic to the nitrifying bacteria.

27. Nutman (P. S.). 1950. *Influence of strain and host factors on the efficiency of nitrogen fixation in red clover.* (Proc. Brit. Comm. Specialist Conference in Agriculture, H.M.S.O., London.)

This paper summarises what is at present known of the factors concerned in symbiotic nitrogen fixation which are subject to mutation. On the basis of genetic analysis of host and strain factors a theoretical model is proposed for the essential intracellular reactions involved in determining whether a particular symbiosis is effective or ineffective in nitrogen fixation. It is suggested that these processes are not special reactions concerned only with nitrogen fixation but are also associated with the normal and essential metabolism of hosts and bacteria, and that in an ineffective symbiosis these reactions mutually interfere and lead to the complete breakdown of the metabolism of the bacteria and of the infected plant cell.

28. Singh (B. N.). 1950. *A culture method for growing small free-living amoebae for the study of their nuclear division.* (Nature, **165**, 65.)

A culture method of growing small free-living amoebae on thin films of non-nutrient agar made on slides as described. After fixation the film is removed, leaving the majority of the amoebae stuck on the glass. As the amoebae are confined to a small area on the slide, it is easy to look for the stages of nuclear division after staining.

29. Skinner (F. A.). 1950. *Preparation of standardised actinomycete colonies.* (Nature, **166**, 314.)

Description of a method whereby actinomycete colonies of standard size and shape may be obtained on agar media by the use of small open-ended porcelain cylinders to confine the inoculum.

30. Skinner (F. A.). 1950. *A method for distinguishing between viable spores and mycelial fragments of actinomycetes in soils.* J. Gen. Microbiol.) [In the press.]

When a suspension of vegetative actinomycete mycelium is shaken violently with sand, the mycelium breaks up into a large number of viable fragments. These fragments are killed if the shaking is prolonged. Spores do not break into smaller viable particles and are killed only with difficulty when shaken under the same conditions. It is, therefore, possible to distinguish suspensions of vegetative mycelium from those of spores by observing the manner in which the viable count varies with the time of shaking. It is not possible to estimate the number of spores and vegetative particles in mixed suspension but the predominating form may be identified. Large numbers of actinomycetes are present in soil samples taken from Broadbalk field, but the evidence obtained from shaking experiments suggested strongly that they were present as free spores.

31. Thornton (H. G.) and Kleczkowska (Janina). 1950. *Use of antisera to identify nodules produced by the inoculation of legumes in the field.* (Nature, **116**, 1118.)

The method is described in which the effect of inoculum of *Rhizobium trifolii* on Montgomery red clover in field conditions was estimated by application test.

Two effective bacterial strains "Cl.F." and "205" belonging to the serological groups seldom present amongst the *Rhizobium trifolii* were used for inoculum. When nodules were produced the plants were harvested at random from inoculated and uninoculated plots. Bacteria were isolated at

random from ten nodules and application tests were made. From inoculated plots strain " Cq.F." gave positive response with specific antisera in about 55 per cent, strain 205 in about 15 per cent, and control plots gave about 1 per cent, with antiserum against " C1.F." and 2 per cent with antiserum against 205 strain.

Botany Department

32. HUMPHRIES (E. C.). 1950. *The absorption of ions by excised root systems. I. Apparatus and preliminary experiments.* (J. Exp. Bot., **1**, 282-300.)

An apparatus is described by means of which the absorption of ions from a complete nutrient solution of constant composition by excised root systems of plants, grown under known nutrient deficiencies, may be measured in standard conditions of aeration and temperature. Results of some preliminary experiments are described.

It was found that the roots readily absorbed the element in which they were deficient, but tended to lose those elements which were already present in normal amounts.

There was almost invariably a loss in fresh weight of the roots after the absorption period and also a loss in dry weight. This loss appears to be complex and is partly attributable to loss of respiratory material.

The addition of 2 per cent sucrose to the solution from which the root systems of phosphorus-deficient barley plants were absorbing increased the nitrogen and phosphorus contents of the roots and maintained the potassium content, while in the absence of sucrose only the phosphorus content increased, but this increase was significantly less than in the presence of sucrose.

It was demonstrated that roots excised from plants growing in soil were capable of absorbing phosphorus or nitrogen—elements in which they were apparently deficient.

The interpretation of data obtained from excised roots is discussed, and it is concluded that excised roots from plants grown in complete nutrient are not likely to behave in the same way as regards absorption as corresponding roots of intact plants, but that roots grown under conditions of deficiency will behave rather similarly whether excised or intact. This fact provides a potential method for diagnosing and evaluating nutrient deficiencies.

The low-salt condition of roots postulated by Hoagland and Broyer is not necessarily the primary requisite for rapid absorption of a particular ion. It is rather that the roots should be deficient in that ion. The roots could be high in other salts.

33. THURSTON (Joan M.). 1950. *A comparison of the growths of wild and of cultivated oats in manganese-deficient soils.* (Ann. App. Biol., **88**, 289-302.)

Two species of wild oats, *Avena fatua* and *A. ludoviciana* and two varieties of cultivated oats were grown to maturity in pots of manganese-deficient soil with and without added manganese.

A. ludoviciana showed different leaf symptoms of manganese deficiency from *A. fatua* and the cultivated varieties. In other respects wild and cultivated oats were similar in their responses to the level of manganese supply, though differences were observed in the severity of the effects. The relative susceptibility to manganese deficiency of the wild and cultivated oats differed according to the effect considered. The total dry weight at harvest is an integration of all the preceding effects on growth and is therefore presumably the best single criterion for determining susceptibility to manganese deficiency. On the basis of per cent loss of total dry weight at harvest, due to lack of manganese, *A. fatua* is judged less susceptible and *A. ludoviciana* more susceptible than the two cultivated varieties and no distinction can be made between the latter.

The most interesting differences between wild and cultivated oats in response to the level of manganese supply occurred in seed production. Manganese-deficient wild oats showed a smaller reduction in the number of seeds formed but a greater reduction in the size and manganese content of individual seeds than the cultivated varieties.

Manganese deficiency lowered the percentage of viable seeds and the percentage of dormant seeds produced by both *A. fatua* and *A. ludoviciana*.

34. THURSTON (Joan M.). 1950. *The wild oat problem.* (Farming, **4**, 332-4.)

The distinguishing characters of *A. fatua* and *A. ludoviciana* are described and possible methods of controlling wild oats are discussed in the light of present knowledge of the biology of the two species.

35. WARINGTON (Katherine). 1950. *The effect of variations in calcium supply, pH value and nitrogen content of nutrient solutions on the response of lettuce and red clover to molybdenum.* (Ann. App. Biol., **37**, 617-23.)

The quantity of calcium supplied did not affect the response of the plants to molybdenum, though the calcium requirement was greater in solutions at pH 4·4 than at 6·3. Growth was best in the more acid of a range of solutions from pH 4·2 to 8·2, in spite of a rapid levelling up to a pH between 6 and 7, but with the possible exception of the solution at 8·3, the need for molybdenum was unaffected by the reaction of the medium. When the calcium supply and/or the initial pH value of the solution was varied, the effect of molybdenum was most pronounced in the largest plants. A reduction in the nitrogen supply delayed the response of lettuce to molybdenum, but with both inoculated or uninoculated clover the reverse was true. This difference in behaviour is explained on the assumption that lettuce has a smaller requirement for molybdenum than clover. Five or 10 p.p.m. Mo was of no more benefit than 0·1 p.p.m. at any level of nitrogen supplied, though the liability to damage from toxicity was possibly greater when nitrogen was plentiful.

36. CROOK (E. M.) and WATSON (D. J.). 1951. *Studies on the storage of potatoes, II. The temperature conditions inside potato clamps.* (J. Agric. Sci., **40**, 199-226.)

Continuous records of the temperature of potatoes stored in clamps were made in 1942-3 (1 clamp) and in 1943-4 (3 clamps). In the first year, the temperatures at various positions in the clamp coverings were also recorded.

The temperature at the middle of the potato heap showed a drift with time similar to that of mean air temperature. Deviations of mean air temperature from smooth trend, lasting for about a week, had no effect on the temperature of the potatoes; longer-period deviations were reflected in the temperature of the potatoes after a lag of about a week. The difference in weekly mean temperature between potatoes and external air averaged about 1–5°C in 1943-4. In 1942-3 it was greater, increasing to over 20° in April, because bacterial rotting of the potatoes following blight infection increased the rate of heat production and caused the clamp to collapse at the end of April.

In two of the 1943-4 clamps (variety Majestic) the potatoes were exposed to temperatures sufficiently low to cause sweetening for several weeks during February and March. In the third clamp (variety Arran Banner) the temperature of the potatoes never fell below 6°. This difference may have been due to greater heat production by Arran Banner than by Majestic, associated with earlier sprouting.

The temperature in the potatoes tended to fall from the centre of the heap towards the outside, but the temperature gradients across the clamp varied with time and between clamps.

The diurnal temperature wave at the outer surface of the earth cover, caused by absorption of heat from solar radiation during the day and loss of heat during the hours of darkness, penetrated through the earth cover but failed to pass the junction between earth and straw. No diurnal wave was detectable in the straw cover or in the potatoes.

Three effects of wind were distinguished:

1. Wind depressed the temperature of the potatoes at the surface of the heap towards which it was blowing, and raised the temperature at the opposite surface. This occurred in the late stages of storage and was attributed to the earth cover becoming sufficiently dry to permit the passage of external air through it. Southerly winds had a greater effect than northerly winds of equal velocity, presumably because the earth cover dried more rapidly at the south face of the clamp than at the north face. Temperature within the straw cover was affected in the same way as that of the potatoes.

2. The daily temperature range throughout the earth cover and in the air was reduced by wind blowing from any direction.
3. After the earth cover was removed from a clamp, in April, 1944, wind greatly increased the diurnal temperature fluctuation at the surface of the potatoes on the side of the clamp towards which the wind was blowing, and suppressed it on the opposite side.

It is concluded that the chief barrier to the penetration of external temperature fluctuation lies at the junction of the earth and straw covers, and that the thickness of the coverings is therefore not very critical.

In general, clamp storage in eastern England provides temperature conditions reasonably close to the optimum only during the months from November to April in winters free from prolonged frosts.

37. Crook (E. M.) and Watson (D. J.). 1951. *Studies on the storage of potatoes, III. The composition of the atmosphere in a potato clamp.* (J. Agric. Sci., **40**, 227-32.)

The CO_2 concentration in the atmosphere of a potato clamp varied between 0·06 and 0·86 per cent. The sum of CO_2 and oxygen concentrations remained approximately constant at 21 per cent. The CO_2 concentration increased with time from December to April. This was attributed to increase in the rate of respiration of the potatoes caused by rise of temperature. Wind blowing in the direction normal to the face of the clamp reduced the CO_2 concentration, presumably by causing external air to flow through the clamp coverings. A multiple regression of CO_2 concentration on temperature of the potatoes at the time of sampling, and on the mean component of wind velocity normal to the calmp face estimated over a period of 3 hours before the time of sampling, accounted for 64 per cent of the variance between sampling occasions.

Unsaturated compounds were detected in the clamp atmosphere by absorption in bromine; the concentration of these, expressed as ethylene varied between 0·004 and 0·025 per cent.

The magnitude of CO_2 accumulation and oxygen depletion in the clamp atmosphere was too small to produce effects of practical importance on the storage of the potatoes. If the unsaturated compounds were ethylene, the concentration present was sufficient to cause appreciable retardation of sprouting.

38. Watson (M. A.) and Watson (D. J.). 1951. *The effect of infection with beet yellows and beet mosiac viruses on the carbohydrate content of sugar beet leaves and on translocation.* (Ann. App. Biol., **38**, 276-288.)

The loss of total carbohydrate (sugars and starch) per cent of residual dry matter (dry matter less total carbohydrate) during a period of darkness from leaves of sugar beet plants infected with yellows virus was as great as that from leaves of healthy plants. The conclusion of previous workers, based on the results of the Sachs iodine test for starch and the occurrence of phloem gummosis in infected plants, that starch accumulates in infected leaves because translocation is prevented by blockage of the sieve-tubes, is therefore incorrect.

Older leaves of infected plants had a higher content of reducing sugars and sucrose, and usually but not invariably of starch, both at the beginning and end of the dark period, than comparable leaves of healthy plants. By far the greater part of the increase was in reducing sugars. In leaves taken in late September from infected plants growing in the field, 20 per cent or more, of the total dry matter, was present as reducing sugars. The reducing sugars in both healthy and yellows-infected leaves were shown by paper chromatography to be glucose and fructose in approximately equal amounts.

The carbohydrate content of sugar beet leaves was little affected by infection with beet-mosaic virus.

Yellows-infected leaves had a lower water content per cent of fresh weight than healthy leaves. This was accounted for by the higher carbohydrate content of infected leaves, for the ratio of water: residual dry matter was not affected by infection or was slightly reduced. This implies that hydration was independent of carbohydrate content.

Statistics Department

39. Boyd (D. A.) and Dyke (G. V.). 1950. *Maincrop potato growing in England and Wales.* (N.A.A.S. Quarterly Review, No. 10, 47-57.)

The Survey of Maincrop Potatoes, initiated in 1948 by the Agricultural Improvement Council, provides detailed data on commercial potato growing methods in England and Wales, together with estimates of yield based on sample liftings. It is shown that official estimates of yield in 1948 and 1949 were one and three-quarter tons per acre below the sample figure.

Examination of the survey data together with summaries of results of experiments shows that growers' practice is mainly satisfactory but improvements in total production might be achieved by earlier planting and better use of farmyard manure.

The need is stressed for further experiments comparing first, early and late planting and second, certified and once-grown seed.

40. Grundy (P. M.). 1951. *A general technique for the analysis of experiments with incorrectly treated plots.* (J. R. Statist. Soc.) [In the press.]

Occasionally in field experiments the wrong treatment is accidentally applied to one or more plots, and as a result difficulties occur in the statistical analysis. The special methods hitherto devised for such cases are of restricted scope. This paper gives a flexible technique for dealing with such disturbances in a variety of different experimental designs. The new method is based on the formulation of a problem which may be regarded as a generalization of both the disturbed and undisturbed designs. The analysis falls into two stages, of which the first (the solution of the generalized problem) is formally similar to a missing-plot analysis. In the second stage, the necessary constraints are applied to the estimates obtained from the first stage. The principles underlying this method are discussed, and different aspects of the technique illustrated by examples ; one of these is the 1947 Rothamsted experiment on the effects of organic manures on potatoes.

41. Healy (M. J. R.). 1950. *The planning of probit assays.* (Biometrics, **6**, 424-431.)

Graphs are presented from which the number of test subjects necessary to achieve a desired degree of precision in a 2 × 3-point probit assay may be determined.

42. Healy (M. J. R.). 1951. *Statistical appendix to paper by F. M. P. Eikstein, P. Krohn and S. Zuckerman, the potency of different oestrogens in monkeys.* (J. Endocrinol.) [In the press.]

The main paper described a large experiment in the induction of artificial oestrus in monkeys by means of synthetic oestrogens, the results of which showed a high degree of non-orthogonality and other irregular features. The appendix describes the methods of analysis adopted, and discusses some points that arise in the handling of this kind of data.

43. Yates (F.). 1950. *The place of statistics in the study of growth and form.* [A discussion on the measurement of growth and form. Under the leadership of S. Zuckerman, F.R.S.] (Proc. Roy. Soc., Series B, **137**, 479-488.)

This paper discusses the functions of statistics in the study of growth and form. Much of the statistical work involved in such study consists of the fitting of some mathematical relation to the observed data. The various objectives of such fitting and the limitations to which deductions based on the fitting are subject are discussed. The statistical processes that are appropriate to the handling of simultaneous measurements on a number of characteristics are also briefly discussed.

44. Yates (F.). 1951. *Manuring for higher yields. Contributions to symposium* : Four thousand million mouths : scientific humanism and the shadow of world hunger, edited by F. le Gros Clark and N. Pirie. (Oxford University Press.) [In the press.]

This paper discusses the part played by scientific manuring in the increase of crop yield and the problems that arise in the planning of the agriculture of

a region so as to lead to the maximum production of human food. The experience of Great Britain in the use of fertilizers and in agricultural planning is taken as an illustrative example.

45. YATES (F.). 1951. *The influence of* Statistical Methods for Research Workers *on the development of the science of statistics.* (J. Amer. Stat. Assoc.) [In the press.]

R. A. Fisher's *Statistical Methods for Research Workers* was first published 25 years ago. The book is of particular interest to Rothamsted since it was written by Fisher after five years' work at the Station and embodies the results of Fisher's researches during his early years there. The paper contains a critical review of the influence of the book on the development of the science of statistics and experimental design.

CORRESPONDENCE AND REVIEWS

46. HEALY (M. J. R.) and LEECH (F. B.). 1950. *Statistical analysis of results for successive tests on the same organism.* (Letter to Nature, **166**, 319.)

47. YATES (F.). 1950. *Review of* The theory of inbreeding, by R. A. Fisher. (Eugenics Review, **42**, 158.)

48. YATES (F.). 1951. *Review of* Experimental designs, by William G. Cochran and Gertrude M. Cox. (Science Progress.) [In the press.]

REPORTS

48a. LORD (Rowena). 1950. *Survey of Fertilizer Practice Report : The Culm Measures, Devon.*

48b. POULTON (Emily P.). 1950. *Survey of Fertilizer Practice Report : The Chalklands of Berkshire.*

49. REES (D. H.). 1950. *Experiments on the feeding of sugar beet and fodder beet to pigs.* (Memorandum prepared for the Animal Experiments Sub-Committee of the Agricultural Improvement Council.)

50. YATES (F.). 1950. *Operational research.* (Prepared for the 4th Session of the United Nations Sub-Commission on Statistical Sampling.)

Plant Pathology Department

GENERAL PAPERS

51. BAWDEN (F. C.). 1950. *Interference phenomena with plant and bacterial viruses.* (*In* Viruses1950, edited by M. Delbruck, Calif. Inst. Technology, pp. 30-34.)

52. BAWDEN (F. C.). 1950. *Some properties of the tobacco necrosis viruses.* (Seventh Int. Bot. Cong.)

53. BAWDEN (F. C.). 1951. *The multiplication of viruses.* (Sci. Progr. **39**, 1-12.)

54. BAWDEN (F. C.) and PIRIE (N. W.). 1950. *The varieties of macromolecules in extracts from virus-infected plants.* (*In* Viruses 1950, edited by M. Delbruck, Calif. Inst. Technology, pp. 35-39.)

55. GLYNNE (Mary D.). 1950. *Factors affecting the incidence of eyespot,* Cercosporella herpotrichoides *Fron. on cereals.* (Seventh Int. Bot. Cong.)

56. GLYNNE (Mary D.). 1950. *Close cereal cropping. Effect of cultural treatments of wheat on eyespot, lodging, take-all and weeds.* (Agriculture, **56**, 510-514.)

57. GREGORY (P. H.). 1950. *Factors controlling plant disease gradients.* (Seventh Int. Bot. Cong.)

58. Hull (R.). 1950. *Some factors affecting the incidence of yellows virus in sugar beet in Great Britain.* (Seventh Int. Bot. Cong.)

59. Hull (R.). 1950. *Virus yellows in sugar beet.* (Farming, **4**, 72-77.)

60. Hull (R.). 1950. *Virus yellows ; need for healthy stecklings.* (British Sugar Beet Review, **18**, 107-111.)

61. Watson (Marion A.). 1950. *Behaviour of persistent and non-persistent aphid-transmitted plant viruses.* (Seventh Int. Bot. Cong.)

RESEARCH PAPERS

62. Bawden (F. C.) and Nixon (H. L.). 1951. *The application of electron microscopy to the study of plant viruses in unpurified plant extracts.* (J. Gen. Microbiol, **5**, 104-109.)

Rods of variable lengths occurred in sap from plants infected with tobacco mosaic, cucumber mosaic, potato X, potato Y, henbane mosaic, tobacco etch, and cabbage blackringspot viruses ; the first two were about 15 mμ wide and appeared rigid, the others were about 10 mμ wide and apparently flexible. Sap from plants infected with tomato bushy stunt, tobacco ringspot and two tobacco necrosis viruses contained spherical particles about 26 mμ in diameter ; two particles, one about 18 mμ and the other about 37 mμ in diameter, occurred in sap from plants infected with a third tobacco necrosis virus. No specific particles were identified in sap from plants infected with tomato spotted wilt, potato leaf roll, cauliflower mosaic, tomato aspermy, sugar beet mosaic and sugar beet yellows viruses. Serologically related strains of any one virus were morphologically indistinguishable, but this has little diagnostic value because so also were some unrelated viruses.

63. Bhargava (K. S.). 1951. *Some properties of four strains of cucumber mosaic virus.* (Ann. App. Biol., **38**.)

Different strains of cucumber mosaic virus differ in their host range, symptoms caused, virulence towards different plants, transmissibility by aphids, dilution end-point and thermal inactivation point.

There are seasonal variations in the susceptibility of some host species ; French bean is apparently immune during summer but during winter produces countable local lesions suitable for quantitative assays.

Different host species differ in the ease with which cucumber mosaic virus is transmitted to and from them ; systemic infection in beet rarely occurred unless the virus was introduced into young tissues. Inhibitors of infectivity in sap of sugar beet and *Phytolacca* sp. make mechanical transmission from these to other hosts difficult ; the inhibitors interfere less with the infection of hosts in which they occur than with infection of tobacco.

Cucumber mosaic virus has a low temperature coefficient of thermal inactivation and much infectivity is destroyed by heating at temperatures below the thermal inactivation point.

Myzus persicae (Sulz.) is a more efficient vector than *Myzus ornatus* (Laing), which is more efficient than *Macrosiphum euphorbiae* (Thomas) ; although individual aphids could cause more than one infection, most cease to be infective in feeding periods of from one to five minutes.

64. Broadbent (L.). 1950. *The microclimate of the potato crop.* (Q. J. Roy. Met. Soc., **76**, 439-454.)

Shade temperatures and humidities in a standard screen and at an arbitrary level of 15 cm in potato crops were continuously recorded during three summers, 1947-49.

In dry sunny periods :

1. the maximum temperature in the crop was from 0° to 13°F higher than in the screen, and over a period of eleven weeks in 1947 averaged 6°F higher ;
2. the crop minimum was about 2°F lower than in the screen ;
3. over a period of five weeks in 1949 the average daily mean temperature in the crop was 2·2°F higher than in the screen, and
4. the average daily temperature range was 8°F greater than in the screen.

Wind, wet soil and cloudy weather greatly reduced these contrasts ; occasionally the crop minimum was higher than the screen minimum.

By day, humidity was higher in the crop than in the screen, the average difference at the minima being 5 per cent in relative humidity, and 7°F in dew point. By night, the dew point in the crop was, on average, 2°F lower than in the screen, corresponding to the observed difference in mean minimum air temperatures.

During 1948 and 1949, more precise discontinuous records were taken of temperature, humidity and wind speed in and above potato crops with different densities of foliage in a variety of weather conditions. Temperature and humidity were measured at 10, 20 or 30, and 60 cm ; wind at 20, 30 and 200 cm above ground level. In the crop there was only a slight temperature gradient in the early morning and throughout cloudy days, but during sunny days gradients were produced, depending on crop density ; it was hottest at 10 cm in an open crop, at 30 cm in a dense crop ; in both it was usually coolest at 60 cm when the soil was dry, but over wet soil the lowest temperature was found at 10 cm. Except on cloudy days, temperature inversion took place before sunset whatever the foliage density or moistness of the soil.

Humidity (dew point) was usually greatest at 10 cm, but in a dense crop over dry soil water vapour transpired from the leaves often caused the air at 30 cm to be more humid than that at 10 cm.

Wind affected both temperature and humidity by increasing lapse rates and causing rapid fluctuations within the crop, particularly of humidity. Changes of wind speed within the crop took place every few seconds, the amplitude of the fluctuations depending on the speed of the wind above the crop.

65. Broadbent (L.), Chaudhuri (R. P.) and Kapica (L.). 1950. *The spread of virus diseases to single potato plants by winged aphids.* (Ann. App. Biol., **37**, 355-362.)

Young potato plants in pots exposed in the open near plots of potatoes for limited periods at intervals during the summer, became infested with large numbers of winged aphids only during warm, calm and dry weather. Although visited by aphids during May and June, when much of the spread of viruses occurred in nearby potato crops, few of the potted plants became infected. Most potted plants became infected in July when alate aphids were leaving neighbouring potato crops. Widely different proportions of the exposed plants became infected in different years ; in two of the three years, many more plants were infected with virus Y than with leaf roll virus.

66. Broadbent (L.), Gregory (P. H.) and Tinsley (T. W.). 1950. *Roguing potato crops for virus diseases.* (Ann. App. Biol., **37**, 640-650.)

Removing virus-infected plants from plots of Majestic potatoes at Rothamsted on 2nd July did not reduce the spread of leaf roll but reduced rugose mosaic (potato virus Y) to about one-fifth of that in plots rogued on 21st July or left unrogued. Roguing Arran Pilot potatoes on 16th June, or 2nd July reduced leaf roll to five-sixths of that in unrogued plots ; roguing on 16th June reduced rugose mosaic to about half that in plots rogued on 2nd July, and about a quarter of that in unrogued plots. Lifting Arran Pilot potatoes in mid-August reduced virus diseases to about two-thirds.

Roguing flattened the gradient (decrease in percentage plants diseased with increasing distance from the source of infection) with rugose mosaic, but had little effect with leaf roll. Evidently any plants prevented by roguing from contracting virus Y were near the initially infected plants.

In 1948 Majestic and King Edward potatoes at three places were rogued during 22nd-24th June and tubers were dug during 28th-30th July and again at the end of the season. Leaf roll spread more in Majestic than in King Edward, and rugose mosaic spread more in King Edward. Roguing reduced the spread of both by about one-fifth at Rothamsted, but had no effect at Sutton Bonington. At Bretton, in the Derbyshire hills, roguing had no effect on leaf roll, but prevented the spread of rugose mosaic.

The small benefit occasionally achieved by roguing in the ware-growing districts of England does not make the practice economically worth while.

67. Broadbent (L.) and Tinsley (T. W.). 1951. *Experiments on the colonisation of potato plants by apterous and alate aphids in relation to the spread of virus diseases.* (Ann. App. Biol., **38**.)

Batches of potato plants in pots were placed in the field for limited periods among plants infected with potato virus Y and leaf roll virus. Some

of the potted plants were surrounded by sticky boards which prevented apterous aphids from reaching them. Almost as many plants within the boards as without became infected, indicating that most of the spread of virus was by winged aphids.

Apterae were probably responsible for spreading the viruses throughout a hill after one or more stems were infected. They may carry infection to neighbouring plants, but most of these will have been infected already by alate.

The number of plants contracting infection was unaffected by watering.

68. GLYNNE (Mary D.). 1950. *Sharp eyespot as a severe disease of oats.* (Nature, **166**, 232.)

Sharp eyespot caused by *Corticium* (*Rhizoctonia*) *Solani* is known as a common but not severe disease of wheat. It is here recorded as causing a severe disease in a crop of oats. Isolates from wheat, inoculated into wheat, barley, oats and rye in sand culture, produced lesions on all four cereals, but oats and rye were much more severely affected than wheat and barley, the fungus penetrating more deeply into their tissues and killing about half the inoculated seedlings.

69. GREGORY (P. H.). 1950. *Deposition of air-borne particles on trap surfaces.* (Nature, **166**, 487-488.)

Examples are given from experiments both in a wind tunnel and in the open air of the efficiency with which sticky traps in the form of vertical cylinders and plates remove spores of *Lycopodium* and *Lycoperdon* from wind sweeping their surface. Efficiency is below 1 per cent for the small spores of *Lycoperdon* under the conditions tested. Tests with horizontal traps of the type employed in pollen studies have shown that deposition at higher wind speeds tested must result mainly from turbulence and not as previously assumed from sedimentation under gravity. For example, with *Lycopodium* in a wind of approximately 9 m./sec. the same number of spores may be deposited on the lower surface as on the upper surface of a horizontal slide.

70. GREGORY (P. H.) and NIXON (H. L.). 1950. *Electron micrographs of spores of some British Gasteromycetes.* (Trans. Brit. Mycol. Soc., **33**, 359-361.)

Spores of some British Gasteromycetes have been examined with the electron microscope. The increased resolving power and great depth of focus enable details of the surface ornamentation to be studied, but the low penetrating power of the 50 kV. electrons used does not permit any internal structures to be seen. The spores of some species which were previously described as smooth are shown to be warted, and the warts on all species examined appear to conform to the same basic pattern. This consists of a low truncated cone having an angle of 45–70° capped by a much flatter cone, the shape of which varies among the different species. To account for the formation and shape of the warts, and also for the presence of circular discs about 0·2 μ diameter, sometimes observed in mounts from immature specimens, it is suggested that, during the disintegration of the gleba, the spores are coated with a gelatinous film which shrinks and cracks while drying.

71. KASSANIS (B.). 1950. *Heat inactivation of leaf-roll virus in potato tubers.* (Ann. App. Biol., **37**, 339-341.)

When potato tubers were stored at 37·5°C. in a humid atmosphere, some lost their germinating power after 20 days but others survived up to 40 days. All tubers infected with leaf-roll virus that survived 25 days at this temperature produced healthy plants. Similar treatments up to 40 days did not free tubers from potato viruses X and Y.

72. KLECZKOWSKI (A.). 1950. *Restoration of the ability of some heated antisera to flocculate specifically their antigens.* (Brit. J. Exp. Path., **31**, 145-154.)

The ability of some antisera to flocculate, i.e. precipitate or agglutinate, their antigens, which is lost by heating, can be restored by incubation with trypsin. The restoration occurs because complexes, formed between antibodies and other serum proteins during the initial stages of heat denaturation, are disaggregated. Trypsin also causes some changes in the molecules of heat-denatured antibodies, probably reducing their size. The changed antibodies still combine specifically with their antigens, but whether or not the

combination leads to flocculation depends on the character of the antigen. Tobacco mosaic virus, tomato bushy stunt virus and a strain of clover nodule bacteria were flocculated by trypsin-treated, heat-denatured antibodies, but horse serum albumin was not.

73. Kleczkowski (A.) and Kleczkowski (Janina). 1951. *Ability of single phage particles to form plaques and to multiply in liquid cultures.* (J. Gen. Microbiol, **5**, 346-356.)

The results of testing a bacteriophage to a strain of clover nodule bacteria using young (1 day) and old (5 days) bacterial cultures both fit to the hypothesis that phage multiplication can be initiated by single phage particles. As the same phage preparations gave more plaques on solid media and higher proportions of liquid cultures in which phage multiplication could be detected with young than with old bacterial cultures, the fit to the hypothesis is not evidence that every single phage particle will multiply. It may be so when young bacterial cultures are used, although there is no positive evidence for it. With older bacterial cultures definitely only a proportion of viable phage particles succeed in starting phage multiplication, the proportion decreasing with the increasing age of bacterial cultures used for testing.

74. Roberts (Florence M. L.). 1950. *The infection of plants by viruses through roots.* (Ann. App. Biol., **37**, 385-396.)

Roots of young tomato plants became infected when inoculated with tomato bushy stunt, tobacco mosaic, and potato X viruses. Root infections also occurred when these viruses were added to soil or culture solutions in which plants were growing.

The viruses were sometimes localized around their initial entry points in roots ; sometimes they invaded the root system but not the shoots, and sometimes they produced full systemic infection of roots and shoots. In some experiments, but not all, systemic infections were more frequent when the upper tap root or superficial roots were inoculated than when fibrous roots were inoculated.

In both tomato and potato, virus X spread from diseased to healthy plants sharing the same culture solution, if their roots were in contact, but not otherwise. Infection of the roots of potato plants by inoculation, produced only one plant with virus-infected haulms, although several had infected tubers.

Biochemistry Department

75. Bawden (F. C.) and Pirie (N. W.). 1950. *Some factors affecting the activation of virus preparations made from tobacco leaves infected with a tobacco necrosis virus.* (J. Gen. Microbiol., **4**, 464-481.)

Preparations of the Rothamsted tobacco necrosis virus were made by the ultracentrifugation of sap from infected tobacco leaves after a preliminary concentration by freezing. Not all the anomalous nucleoprotein in these preparations was infective, and the products were fractionated by differential ultracentrifugation at lower speeds and by precipitation at pH 4 in the presence of sedimentable protein from uninfected leaves. The more readily sedimentable and precipitable material carries with it most infectivity, whereas the other has the greater serological activity.

Preparations made quickly from freshly expressed sap are less infective than those made from sap that has been frozen or allowed to age for a few days. The extent of the activation produced by these treatments depends on the physiological condition of the infected leaves.

As much virus can be extracted from the leaf residues as occurs in the sap. The infectivity of this residual virus depends on the medium used for its extraction.

It is suggested that much of the infectivity of this virus in sap is acquired during or after extraction from the leaf, but the relationship between the particles with different sizes and properties remains uncertain.

76. Bawden (F. C.) and Pirie (N. W.). 1950. *Some effects of freezing in the leaf, and of citrate* in vitro, *on the infectivity of a tobacco necrosis virus.* (J. Gen. Microbiol., **4**, 482-492.)

Preparations of the Rothamsted tobacco necrosis virus made from tobacco leaves that have been frozen while intact are less infective than

preparations made from unfrozen leaves. Freezing minced leaves or expressed sap does not destroy infectivity. The suggestion is made that much virus in the intact leaf becomes infective only by means of a mechanism that is set in action by mincing and is disordered by freezing.

The infectivity, but not the serological activity, of the virus is lost on exposure to 0·02–0·01 M neutral citrate; the extent of this inactivation is influenced by the temperature, pH, duration of exposure, concentration of virus and presence of salts and other substances. Similar processes could influence the infectivity of the virus in sap and may do so in the leaf.

77. Grégoire (J.). 1950. *Action de la soude N/30 sur le virus de la mosaique du tabac et sur l'acide nucleique du virus ainsi libéré. 1. Mise en évidence d'un facteur accélérant la perte de précipitabilité de l'acide nucleique et la formation de produits diffusibles.* (Bull. Soc. Chim. Biol., **32**, 359.)

Nucleic acid can be made from tobacco mosaic virus if the linkage between Nucleic acid and protein is broken by exposure for a few minutes at room temperature to N/30 NaOH followed by removal of the denatured protein at pH 5·2 and precipitation of the nucleic acid by strong acid. The nucleic acid, when isolated, is stable for many hours in N/30 NaOH, but if it is left in this environment in the presence of the protein split products it loses its acid precipitability. Evidence is presented that this is due to a depolymerisation of the nucleic acid catalysed by protein derivatives of high molecular weight.

78. Holden (Margaret). 1950. *A study of enzymes that can break down tobacco leaf components. 3. Fungal polygalacturonase on leaf fibre.* (Biochem. J., **47**, 415-420.)

Tobacco leaf fibre incubated at pH 4·5 several times with fresh lots of purified polygalacturonase loses about half of the polyuronide. Milling the fibre increases the rate of release of carbohydrate from fibre with PG and also increases slightly the total amount liberated. Decalcification of fibre by cationic exchange with concentrated salt solutions, and by acid extraction, increases the rate of liberation of carbohydrate by PG, and up to 95 per cent of the polyuronide present is released. NaCl in concentrations $>0·05$ M inhibits PG action on fibre, but lower concentrations $>0·01$–M activate. $CaCl_2$ is inhibitory except in concentrations below about 0·001–M when using decalcified fibre.

79. Holden (Margaret). 1950. *A study of enzymes that can break down tobacco leaf components. 5. Unfractionated fungal enzymes.* (Biochem. J., **47**, 426-431.)

The effects on tobacco leaf fibre of some enzyme preparations of fungal origin have been investigated and compared with those of snail digestive juice. The enzymic activities of the preparations on a number of polysaccharides; cellulose, pectic acid, starch and inulin, and on haemoglobin and gelatin were determined.

80. Holden (Margaret), Pirie (N. W.) and Tracey (M. V.). 1950. *A study of enzymes that can break down tobacco leaf components. 1. Digestive juice of helix on leaf fibre.* (Biochem. J., **47**, 399-407.)

The effect of Helix digestive juice polysaccharidases on tobacco leaf fibre has been investigated. Various pretreatments of the fibre modify the action of these enzymes. 90 per cent of the carbohydrate of the fibre can be brought into solution. The nature of the insoluble residue is discussed. Cellulase and polygalacturonase are principally concerned in this digestion. The action of the latter is favoured by preliminary decalcification of the fibre. Snail digestive juice has little action on the green "chloroplast" fraction of sap sediment. The merits of disintegrating leaves enzymically are considered, but the fact that release by a specific enzyme does not give unequivocal evidence about the original linkage of a substance is recognised.

81. Holden (Margaret) and Tracey (M. V.). 1950. *A study of enzymes that can break down tobacco leaf components. 2. Digestive juice of Helix on defined substrates.* (Biochem. J., **47**, 407-414.)

The action of snail digestive juice on cellulose (cellophane) and pectic acid has been investigated. A number of polysaccharides and polysaccharide

dericatives have been tested as subtrates for snail digestive juice. Hyaluronic acid, alginic acid, a dextran from *Betacoccus* arabinosaceous, " galactogen " from *H. asperoa* and nitrocellulose were not affected, while irisin, yeast glucan, a levan from grass, a bacterial levan, methylcellulose, methylethylcellulose, and carboxymethylcellulose were.

A sensitive method for the detection of cellulase has been developed. The reduction in viscosity of a water-soluble cellulose derivative is used as an index of cellulase activity.

Sodium carboxymethylcellulose is split enzymically to an extent corresponding with the breaking of glycoside links between unsubstituted residues. Methylethylcellulose is split to an extent corresponding with the breaking of glycoside links between residues one of which is unsubstituted.

82. Holden (Margaret) and Tracey (M. V.). 1950. *A study of enzymes that can break down tobacco leaf components.* **4.** *Mammalian pancreatic and Salivary enzymes.* (Biochem. J., **47,** 421-425.)

All starch may be removed from tobacco leaf fibre by incubation with salivary amylase. All starch and about 80 per cent of the total nitrogen can be removed from tobacco leaf fibre by incubation with commercial trypsin. Incubation with commercial trypsin leads to a loss of $CHCl_3$ soluble material parallel with the loss of dry matter. Figures are given for the composition of the particulate matter in crude saps.

83. Pirie (N. W.). 1950. *A biochemical approach to viruses.* (Nature, **166,** 495-496.)

84. Pirie (N. W.). 1950. *The isolation from normal tobacco leaves nucleoprotein with some similarity to plant viruses.* (Biochem. J., **47,** 614-625.)

A nucleoprotein has been prepared from the sap of young uninfected tobacco leaves by ultracentrifugation. The yield varies from 3 g./l. with the sap of immature leaves to 0·1 g./l. or less with large mature leaves, or with sap that has been allowed to age before processing. The nucleoprotein is unstable *in vitro* and autolyses in a few hours at 37° yielding denatured protein and either nucleotides or nucleosides depending on the duration of hydrolysis. The denatured protein still retains some of the enzymes that occur in leaf sap and different preparations have been compared using metaphosphate, glycerophosphate, adenosine triphosphate and yeast nucleic acid as substrates. Reasons are given for thinking that, although it bears some resemblance to them, the nucleoprotein cannot usefully be regarded as a precursor of the plant viruses.

85. Tracey (M. V.). 1950. *Proteins.* (Annual Reports of the Chemical Society for 1949, **46,** 211-228.)

A review concerned with advances in protein chemistry from 1937 to 1949. In the space available only two topics are discussed in detail—the present state of our knowledge of the organic chemistry of β–lactoglobulin and the organic chemistry of synthetic polypeptides.

86. Tracey (M. V.). 1950. *Cellulase from leaves and roots of tobacco.* (Biochem. J., **47,** 431-433.)

An enzyme that can depolymerise sodium carboxymethylcellulose, and split reprecipitated cellulose has been found in tobacco plants. The enzyme, which is similar in properties to animal and fungal cellulases, is present in very low concentrations. It is suggested that this may be explained by its localisation in cells in which reconstruction of the thin primary cell wall is occurring as a concommitant of cell growth.

87. Tracey (M. V.). 1950. *A colorimetric method for the determination of pentoses in the presence of hexoses and uronic acids* (Biochem. J., **47,** 433-436.)

A method for the colorimetric estimation of pentoses in the presence of large amounts of other sugars is described. It is suitable for the determination of 10–100 μg. of xylose. Glucose interference was found to be about 2 per cent and galactose and galacturonic acid interference about 5 per cent. Interference by other sugars tested was less than 1 per cent. The effect of varying conditions on the specificity and sensitivity of the reaction was determined and optimal conditions are described. Increased temperature,

time of development and concentration of aniline all affect colour development by the sugars examined, but not equally. The addition of oxalic acid increases the specificity of the test.

88. KENTEN (R. H.) and MANN (P. J. G.). 1951. *The oxidation of amines by extracts of pea seedlings.* (Biochem. J., **46**, 67-73.)

A colorimetric test, based on the oxidation of added Mn++ to Mn+++ is described for the detection of hydrogen peroxide in plant extracts. By means of this test evidence has been obtained that hydrogen peroxide is produced by enzyme systems present in extracts of many higher plants.

An enzyme, plant amine oxidase, catalysing the oxidation of amines is present in extracts of pea seedlings. With the growth condition used plant amine oxidase appears in pea seedlings, mainly in the cotyledons, 3-4 days after germination, and is maximal over the period 7-18 days. Only slight activity is found in the adult plant. Of the other plants tested only lupin seedlings have so far been shown to have comparable activity. Both mono- and di-amines are attacked by the extracts. It is not yet known whether this is due to the presence of specific mono- and di-amine oxidases. Diamines, in particular putrescine and cadaverine, are more readily attacked than mono-amines. Of the mono-amines tested β–phenylethylamine and di–βphenylethylamine are most readily attacked.

The plant amine oxidase catalyses the oxidative deamination of β–phenylethylamine and putrescine according to the equation:

$$R \cdot CH_2NH_2 + O_2 + H_2O \longrightarrow R \cdot CHO + H_2O_2 + NH_3$$

As with animal diamine oxidase only one of the terminal $-NH_2$ groups is attacked. The phenylacetaldehyde formed by the action of plant amine oxidase on β–phenylethylamine was oxidised by an aldehyde oxidase present in the preparation used. It is suggested that 3–indolylacetic acid may be formed by the successive action of plant amine oxidase and of the aldehyde oxidase on tryptamine.

89. PIRIE (N. W.). 1951. *The circumvention of waste.* (In: *Four thousand million mouths.* Oxford University Press.) [In the press.]

Nematology Department

90. FENWICK (D. W.). 1951. *Investigations on the emergence of larvae from cysts of the potato root eelworm* Heterodera rostochiensis. *IV. Physical conditions and their influence on larval emergence in the laboratory.* (J. Helminth., **25**.) [In the press.]

The influence of preconditioning, temperature, volume of diffusate per cyst, pH, degree of dilution and presence or absence of light on the hatching of the potato root eelworm in root diffusate, is investigated. The effect of these factors on hatchability, mean hatching time and on the slope of the probit line are described in detail and suitable conditions for the conduct of hatching tests are suggested.

91. FENWICK (D. W.). 1951. *Investigations on the emergence of larvae from cysts of the potato root eelworm* Heterodera rostochiensis. *V. A shortened method for the conduct of hatching tests.* (J. Helminth., **25**.) [In the press.]

A method of estimating the three parameters of the hatching curve without carrying on a hatching test to completion is described. Use is made of the fact that the hatching curve plotted against log-time is a symmetrical sigmoid and a geometrical construction is given for estimating the point of inflection. The number of larvae emerging at this point is an estimate of 50 per cent of the final total hatch. The plotting of a complete probit line is thus possible with a saving of 70 per cent in time.

92. FENWICK (D. W.). 1951. *The effect of temperature on the development of the potato root eelworm* Heterodera rostochiensis. (Ann. App. Biol.) [In the press.]

Experiments are described on the effect of temperature on the development of *H. rostochiensis*. Soil temperatures above 20°C. appear to be unfavourable, influencing the penetration of larvae into the potato root as well as development within the root. The temperature range of the parasite is compared with that of *H. marioni* and the possible relationship to the geographical distribution peculiar to each parasite is discussed.

93. Fenwick (D. W.). *A new modification of the MacMaster slide for use in potato root eelworm investigations.* (J. Helminth.) [In the press.]

A new modification of the McMaster slide is described. This version is more stable than any previous type and up to six counting cells can be accommodated in one unit; instructions are given for making such a slide out of sheet perspex.

94. Fenwick (D. W.) and Reid (Elizabeth). *A rapid method for estimating the density of white cysts of* Heterodera rostochiensis *on potato roots.* (Nature.) [In the press.]

A new method of estimating the density of white cyst populations on potato roots to a known degree of accuracy is described.

95. Goodey (J. Basil). 1950. *Potato-tuber eelworm and iris bulbs.* (Nature, **165**, 495.)

A letter to the effect that *Ditylenchus destructor* is responsible for the eelworm disease of bulbous iris.

96. Goodey (J. Basil). *Observations on the attack by stem eelworm on strawberry.* [In the press.]

The history of disease in strawberry caused by *Ditylenchus dipsaci* is summarised and observations made on recent cases in Britain are recorded. Experimental work has shown that populations of *D. dipsaci* from teasel, oats, onion, red clover, narcissus and rye will all infest most of the varieties cultivated to-day. The symptoms manifested by the plant and the methods of attack by the parasite are described.

97. Goodey (T.). 1949. *Plant parasitic nematodes : a brief survey and some present day trends.* (13th Congrès International de Zoologie Paris, 21-27 July, 1949, 481-485.)

In this paper delivered before the 8th section of the Congress covering applied zoology and parasitology, the writer gave a short account of the history of our knowledge of plant parasitic nematodes and dealt with such matters as their means of dispersal in and upon the seeds of plants, the significance of weeds as reservoir hosts in maintaining infestations in the field and with the manner in which the root-knot nematode, *Heterodera marioni*, feeds on the giant cells which are formed within parasitized roots in response to its presence. He also indicated some of the problems associated with plant infestations due to species of *Aphelenchoides*.

98. Goodey (T.). 1950. *Stem eelworm and clover.* (Proc. Ass. App. Biol. in Ann. Appl. Biol., **37**, 324-327.)

The history of stem eelworm infestations of clover in Europe since the early 19th century were dealt with and the chief biological differences between the races affecting rye and oats and that attacking clover were discussed. Symptoms manifested by clover plants infested with the true clover strain of the parasite were described. It was also shown that flower tissues may become attacked and that the parasite can be seed borne in which case control is possible by seed fumigation. The significance of weeds as reservoir hosts and the question of resistant varieties of red clover were briefly touched on.

99. Goodey (T.). 1950. *The clover eelworm observed.* (The Farmers Weekly, **32**, 53 and 55.)

A more popular presentation of No. 10.

100. Goodey (T.). 1950. Article on *Eelworm.* (In *Chambers's Encyclopaedia.*)

101. Peters (B. G.). 1950. *Nematodes as crop parasites.* (World Crops, **2**, 11-15.)

102. Peters (B. G.). 1950. *Controlling potato root eelworms.* (British Farmer, 31st October, 1950.)

103. Peters (B. G.). 1950. *Potato root eelworm.* (Farming, **4**, 338-341.)

104. Peters (B. G.). 1950. *Articles : Cestoda, Nematoda, and Trematoda.* (In *Chambers's Encyclopaedia.*)

Entomology Department

BOOK

105. Barnes (H. F.). 1951. *Gall midges of economic importance. Vol. 5. Gall midges of trees.* (Crosby Lockwood and Son, Ltd. 270 pp. and 8 plates.)

The fifth volume of the series deals with the gall midges of trees in two sections: those of coniferous trees and those of broad-leaved trees. About 300 gall midges receive attention. This volume contains, just as the previous ones, much information of an economic botanical nature.

PUBLICATIONS

106. Barnes (H. F.). 1950. *The need for biological investigations in the specific determination of gall midges.* (Proc. Eighth Int. Cong. Entomology, Stockholm, 106-110.)

A plea for biological investigations as a necessary aid to the correct identification of gall midges, giving, as examples, certain gall midge pests of cereals, cabbage, fruit and grasses as well as those feeding on aphids, coccids and rusts.

107. Barnes (H. F.). 1950. *The identity of the swede midge, with notes on its biology.* (Ann. App. Biol., **37**, 241-248.)

An account of biological experiments which show that the swede midge will attack the flower buds of great watercress (*Rorippa amphibia*) as well as the flower buds and leaves of turnip, swede, cabbage and radish. The correct name for this midge is *Contarinia nasturtii*, Kieffer, 1888 (syn. *Contarinia torquens* de Meijere, 1906; *Contarinia geisenheyneri*, Rübsaamen, 1917). It breeds by means of unisexual families.

108. Barnes (H. F.). 1950. *Worm eating slugs in Bedford gardens.* (Bedfordshire Naturalist, **4**, 23-25.)

A brief illustrated account of observation, weights, feeding and marking experiments on *Testacella haliotidea* and *T. scutulum*.

109. Barnes (H. F.). 1950. *Obituary Notice—Dr. A. D. Imms.* (Ann. App. Biol., **37**, 553-554.)

The late Dr. Imms was the first head of the entomology department.

110. Eastop (V. F.). 1951. *Diurnal variation in the aerial density of Aphididae.* (Proc. Roy. Ent. Soc. Lond. (In the Press.)

The diurnal flight activity (with the double peak of aerial density) and the nocturnal quiescence found to occur in *A. fabae* is described for many other species of aphids.

111. Johnson (C. G.). *The dispersal of insects by wind.* (New Biology, **9**, 76-89.)

112. Johnson (C. G.). 1950. *The study of wind-borne insect populations in relation to terrestrial ecology, flight periodicity and the estimation of aerial populations.* (Sci. Prog., **39**, 41-62.)

This is a critical review of the present state of insect "aerobiology." Hitherto changes in insect populations in the upper air have often been studied by inadequate methods, and attempts have been made to interpret the changes in aerial density solely with meteorological conditions prevailing at the time of capture, without due reference to the correlated changes in terrestrial ecology and flight periodicity at crop level, which are the basis for subsequent aerial changes. This paper describes how the type of work in progress at Rothamsted and Cardington follows hourly and daily fluctuations in density at crop level, and aims to correlate these changes with the build up of vertical density up to 2,000 ft. during the day and its decline at night.

113. Southwood (T. R. E.). 1950. *Deraeocoris scutellaris F. (Hemiptera, Miridae) taken in the light traps at Rothamsted, Hertfordshire.* (Ent. Mon. Mag. **86**, 78.).

114. Taylor (L. R.). 1951. *An improved suction trap for insects.* (Ann. App. Biol.) (In the press.)

The original model of the disc-dropping suction trap (described in Ann. App. Biol., **37**, 80) has certain weaknesses of construction and design. This paper describes an improved design in which these weaknesses are rectified.

115. Williams (C. B.). 1950. *The biology of the seasons.* (New Naturalist J., **2**, 1-14.)

A semi-popular account of the effect of seasonal changes on living creatures, and particularly a discussion on some problems of phenology, or the dates of occurrence of biological events. This is based on a long series of observations made by successive generations of the Marsham Family, in Norfolk, starting in 1740 and lasting with only one break to the present day.

116. Williams (C. B.). 1951. *A note on the relative sizes of genera in the classification of animals and plants.* (Proc. Linnean Soc., London, **162** (2), 171-175.)

A discussion of the application of statistical methods to certain problems of taxonomy and particularly the relative sizes of genera. It is found that in any group of animals or plants the number of genera with one, two, three, etc. species conforms closely to a "logarithmic series." This mathematical test can be used to see if a systematist is "consistent" but not if he is correct. The "lumpers" who allow few genera and the "splitters" who allow many genera for the same number of species, may both be consistent in the application of their principles, and both may be interpreting correctly the relationship of species at slightly different levels.

117. Williams (C. B.). 1951. *Changes in insect population in the field in relation to preceding weather conditions.* (Proc. Roy. Soc. Series B, **138**, 130-156.)

An examination of the results of trapping of insects in light traps during two periods of four years separated by the war. It has been found possible to estimate the population changes from light trap catches by using the geometric mean catch (i.e. mean log) for each month, and then comparing the same month in successive years. This gives a measure of departure of the population from normality for the time of the year.

Using these values as dependent variables, and the rainfall and temperature departures from normal in each of the three previous months as independent variables, it is possible to calculate for each of the four seasons, a series of six regressions. With a knowledge of these it is then possible to estimate or forecast the probable population departure in any one month if the rainfall and temperature of the three previous months is known.

This has been done for the two periods of 48 months each, and the fit of the calculated to the observed change is extremely good. In the summer and autumn months 70 per cent of the variance of the population can be explained. In the winter 50 per cent and in the spring only 25 per cent. The changes in the regression during the four seasons show that rainfall has a high positive effect on the population in summer and autumn, but little effect in winter and spring. Temperature, on the contrary, shows a high positive relation in winter, little relation in spring and autumn, and a slightly negative relation in summer. In other words insects in general are in S.E. England more abundant in warm winters and wet summers, and less abundant in cold winters and dry summers.

118. Williams (C. B.) and Long (D. B.). 1950. *Phase colouration in larvae of Lepidoptera.* (Nature, **116**, 1,035.)

A letter calling attention to the discovery of differences in colouration and behaviour of larvae of *Plusia gamma*, the Silver–Y moth, according to whether they are crowded or kept isolated.

Bee Department

119. Butler (C. G.). 1950. *A new design of microsyringe tip for instrumental insemination of queen honeybees.* (Nature, **166**, 957-958.)

A description of a syringe tip which enables the syringe to be held in the hand throughout the operation of introducing semen into the queen honeybee, and allows of easy introduction of the syringe without the use of a probe.

120. Ribbands (C. R.). 1950. *Autumn feeding of honeybee colonies.* (Bee World, **31**, 74-76.)

Concentrated (66 per cent) sugar syrup, fed to colonies of honeybees in autumn, results in the production of about one-third more ripe stores than does the same weight of sugar fed as dilute (38 per cent) syrup.

The elimination by the bees of each 1 lb. of surplus water from the syrup involved the utilisation of 4-5 oz. of the syrup. This wastage of syrup was not due to brood rearing, which was less when dilute syrup was fed. About 10 per cent more ripe stores resulted from the feeding of concentrated syrup in mid-September than from the feeding of the same amount in August.

121. Ribbands (C. R.). *Changes in the behaviour of honeybees following their recovery from anaesthesia.* (J. Exp. Biol., **27**, 302-310.)

Anaesthesia with choloroform had no effect upon the memory, subsequent foraging behaviour, or longevity of worker honeybees. Anaesthesia with carbon dioxide did not impair the memory but induced a permanent change in the behaviour of worker honeybees, thus the pollen collecting tendencies of bees so treated were either eliminated or markedly reduced. The treatment of newly emerged worker bees with carbon dioxide resulted in a reduction in their brood rearing and wax secreting activities, and caused them to commence to forage at an early age. The treatment had no direct effect upon the longevity of the bees concerned.

The effects of nitrogen anaesthesia were similar to those of carbon dioxide. The factor common to both these treatments is lack of oxygen.

Insecticides and Fungicides Department

122. Elliott (M.), Needham (P. H.) and Potter (C.). 1950. *The insecticidal activity of substances related to the pyrethrins. Part I. The toxicities of two synthetic pyrethrin like esters relative to that of the natural pyrethrins and the significance of the results in the bioassay of closely related compounds.* (Ann. App. Biol., **37**, 490-507.)

The toxicity as contact insecticides of the esters of (±)–3–methyl–2–allyl–*cyclo*pent–2–en–4–ol–l–one with the natural (+)–*trans* and with synthetic (±)–*cis–trans*–chrysanthemum monocarboxylic acids has been compared with that of the natural pyrethrins. The comparison was carried out on five species of test-insects.

It was found that the figure for both the absolute and the relative toxicities of these compounds varied with the species used as test-subjects.

The factors involved in this variation are discussed. The extremes of variation of relative toxicity for the compounds with the natural acid were from about one-eighth as toxic as the pyrethrum standard when the sphid *Macrosiphum solanfolii* was used as test subject to nearly four times as toxic as the standard with the larvae of the moth *Plutella maculipennis*. The fully synthetic material varied from about 1/16 as toxic as the standard to *Macrosiphum solanifolii* to nearly twice as toxic to the larvae of *Plutella maculipennis*. The compound with the natural acid was approximately twice as toxic as the fully synthetic material to three of the insect species, but the fully synthetic material was considerably more than half as toxic as the partially synthetic to the fourth test-species. It is pointed out that while it is widely recognised that large differences in relative toxicity may occur when the effect of chemicals of widely different structure and mechanism of action are compared on a number of different test-species, the fact that these differences may also occur with related chemicals, with presumably a similar mechanism of action, has not been clearly stated.

Even when the differences in relative toxicity are taken into account, the two synthetic pyrethrin-like esters still show high insecticidal activity.

It seems reasonable to suppose from the results that economic commercial synthesis of pyrethrin-like insecticides is not impossible.

123. Way (M. J.) and Hopkins (Barbara). 1950. *The influence of photoperiod and temperature on the induction of diapause in* Diataraxia oleracea *Linn, Lepidoptera.* (J. Exp. Biol., 365-376.)

The induction of diapause in the pupa of *Diataraxia oleracea* is influenced by temperature and photoperiod during the larval stage. Low temperatures

and short photoperiods tend to induce diapause while high temperatures and long photoperiods tend to prevent diapause.

Diapause is not influenced by light intensity during the larval stage providing the intensity is above a certain minimum.

Diapause is prevented at high temperatures (30–34°C.) if the larvae are reared in darkness.

The photoperiod is operative as a factor influencing diapause only between the beginning of the moulting sleep prior to ecdysis to the last instar and the 3rd-5th day of the last instar. A single diapause-preventing photoperiod during the moulting sleep is probably sufficient to prevent diapause.

Diapause in *D. oleracea* is not influenced by photoperiodically controlled substances in the larval food plant.

124. Way (M. J.). 1950. *The structure and development of the larval cuticle of* Diataraxia oleracea (*Lepidoptera*). (Q. J. Mic. Soc., **91**, 145-182.)

The main layers comprising the soft cuticle of the *Diataraxia* larva have been defined and a study made of their formation during development of the 5th instar larval cuticle.

In soft cuticle the epicuticle is thrown into minute tubercles and consists of three layers—the cuticulin layer, the wax layer, and the cement layer. The cement layer lies outside or partly embedded in the wax layer, but it is either absent or extremely thin over the tips of the tubercles. A polyphenol layer is absent and it is suggested that this layer is only present in hard cuticle. Beneath the epicuticle is a thin, lightly tanned exocuticle approximately 0·5 μ thick. The 7–10μ thick outer endocuticle is perforated by well-defined pore canals and consists of lamellae containing chitin fibres varying from 100–2000 Å in diameter. Pore canals are absent in the inner endocuticle, which when fully developed may be 50 μ in thickness.

A description is given of how the cuticle is laid down at the moulting period with an account of the function of the pore canals.

A study of Verson's glands suggested that the large gland cell secretes a lipoprotein which is discharged on the surface of the epicuticle to form the cement layer. The intercalary cell secretes a phenol which is responsible for the tanning of a plug that blocks the opening of the gland directly after discharge.

125. Lord (K. A.) and Potter (C.). 1950. *The mechanism of action of organo-phosphorus compounds as insecticides.* (Nature, **166**, 893-894.)

This is a preliminary publication, full details of which are now in the press, describing studies which have been made on the anti-esterase activity of Parathion, HETP and TEPP using an insect tissue extract. The anti-esterase activity has been compared with insecticidal activity and TEPP content and some correlation between these three factors established. Some evidence is given to show that esterases other than choline esterase may be important when considering the mechanism of action of organo-phosphorus compounds.

126. Lord (K. A.). 1950. *A colour reaction applicable to the pyrethrins.* (Nature, **165**, 567.)

A reaction between carboxylic acid derivatives and hydroxylamine, the product of which gives a coloured complex with ferric chloride in acid solution, was found to apply to the pyrethrins and their synthetic analogues. Details of experimental procedures are given. The absorption spectra of the complexes obtained from a mixture of the natural pyrethrins purified by the nitromethane technique and the synthetic pyrethrin analogue, the d,l,–*cis–trans* chrysanthemum monocarboxylic ester of 3–methyl–2–allyl–*cyclo*penten–4–ol–1–one were measured and found to be closely similar to those of other carboxylic acid derivatives. The possible use of this reaction for the detection and estimation of the pyrethrins and its analogues is discussed.

127. Lord (K. A.). 1950. *The effect of insecticides on respiration. II. The effects of a number of insecticides on the oxygen uptake of adult* Tribolium castaneum *Hbst. at* 250°*C.* (Ann. App. Biol., **37**, 105-122.)

An apparatus for applying insecticidal dusts in a modified Barcroft respirometer is described. Using this technique the initial effects of a number

of insecticides including so-called inert dusts, and other finely divided materials some of which are used as diluents, on the respiration of *Tribolium castaneum* Hbst. was studied.

The effect of humidity on the action of inert dusts, in particular, almicide was also investigated.

Of the insecticides tested, 3 : 5–dinitro–o–cresol (DNC), p–nitrophenyl diethyl thionophosphate (Parathion), γ isomer of benzene hexachloride (γ BHC), DDT, pyrethrins, toxaphene, chlordane, hexaethyl tetraphosphate, all produced an increase in oxygen uptake before killing, but lauryl thiocyanate did not. The effects of different concentrations of insecticide in the dusts was also studied for some of the insecticides.

128. Lord (K. A.). 1950. *The effect of concentration of poison and the amount applied on the toxicity of insecticidal dusts to adult* Tribolium castaneum *Hbst.* (Ann. App. Biol., **37**, 123-126.)

Using insecticidal dusts of DDT, Benzene hexachloride, and DNC under the experimental conditions, comparatively large changes in the amount of material of a given concentration are necessary in order to give appreciable differences in mortality, but small changes in the concentration of the poison will produce large differences in toxicity with a given amount applied. This relationship would appear to hold with a number of insecticides.

129. Lord (K. A.), part author. 1950. *Consultative committee on insecticide materials of vegetable origin. Report of the standing sub-committee of analysis of vegetable insecticides on the world-wide, collaborative analysis of pyrethrum flowers.* (London.)

Woburn Experimental Station

130. Mann (H. H.). 1951. *The effect of manures on the bolting of the beet plant.* (Ann. App. Biol.) [In the press.]
131. Mann (H. H.). 1950. *World cereals to-day : the millets.* (World Crops, **2**, 97.)
132. Mann (H. H.). 1950. *Maize growing for grain in England.* (The Countryman.)

General Publications

133. Oldershaw (A. W.) and Garner (H. V.). 1949. *Liming experiments on light sands at Tunstall. Part 2. The agricultural aspects.* (J. Roy. Agric. Soc., **110**, 89-98.)
134. Garner (H. V.). 1950. *Sugar beet irrigation.* (British Sugar Beet Review, **18**, 145-150.)
135. Garner (H. V.). 1950. *A fertilizer programme for winter wheat.* (British Farmer, September 30th.)
136. Garner (H. V.). 1950. *Liquid manure losses.* (Farmer and Stockbreeder Year Book, 73-75.)
137. Ogg (Sir W. G.). 1950. *Weather and food.* (Centenary Proc. R. Met. Soc., 239-243.)
138. Ogg (Sir W. G.). 1949. *The part played by phosphorus in agriculture.* (Journées du Phosphore, Paris, January 1949.)

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1944 HALL (Sir A. D.). *The feeding of crops and stock.* Parts 1 and 2 revised by Sir W. G. Ogg. 3rd edition. (London, John Murray, 12/-.)

1946 RUSSELL (Sir E. J.). *British agricultural research : Rothamsted.* Revised edition. (London, published for the British Council by Longmans, Green & Co., 1/6.)—A Spanish translation (new impression, 1947, 1/-) and a Portuguese translation (1942, 1/-) are available from the same publishers.

1948 BAWDEN (F. C.). *Plant diseases.* (London, Thomas Nelson & Sons Ltd., 7/6.)

1948 BUTLER (C. G.). *The importance of bees in orchards.* Ministry of Agriculture Bulletin No. 328. (London, H.M. Stationery Office, 9d.)

1948 FISHER (R. A.). *Statistical methods for research workers.* 10th edition. (Edinburgh, Oliver & Boyd, 16/-.)

1948 FISHER (R. A.) and YATES (F.). *Statistical tables for biological, medical and agricultural research.* 3rd edition. (Edinburgh, Oliver & Boyd, reprinted 1949, 16/-.)

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1948 TRACEY (M. V.). *Proteins and life.* (London, Pilot Press ; reprinted by Chapman & Hall Ltd., 10/6.)

1948-1951 BARNES (H. F.). *Gall midges of economic importance.* Volumes 1-6. (London, Crosby Lockwood & Son, Ltd. Vol. 1, 12/6 ; Vols. 2-6, 15/-. Two more volumes will complete the work.)

1949 BUTLER (C. G.). *Beehives.* Ministry of Agriculture Bulletin No. 144. (London, H.M. Stationery Office, 9d.)

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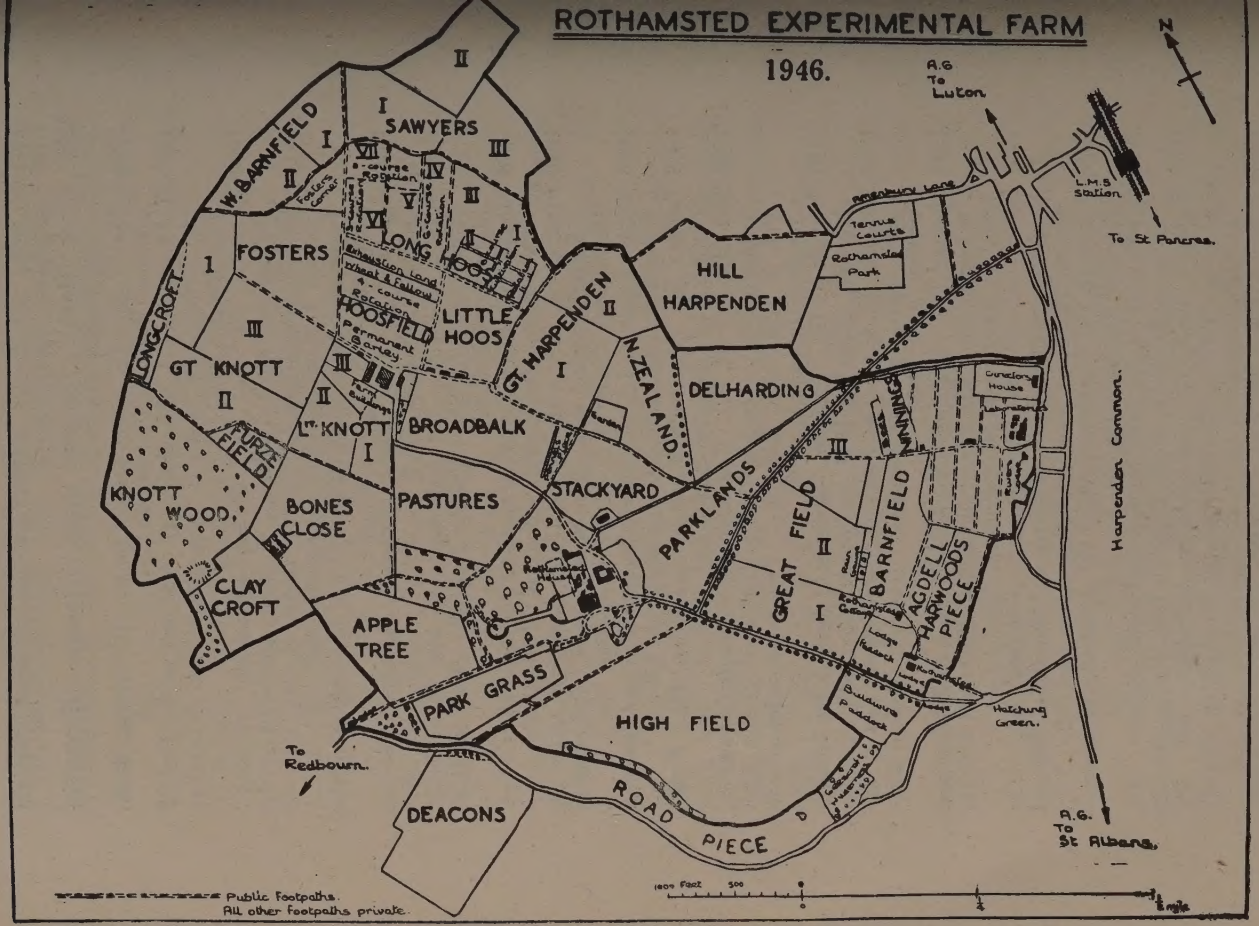
1951 GOODEY (T.). *Soil and freshwater nematodes.* (London, Methuen & Co., Ltd., 45/-.)

* Out of print.


ROTHAMSTED EXPERIMENTAL FARM
1946.
A.6 To Luton
N
L.M.S Station
To St Pancras.
Tennis Courts
Rothamsted Park
HILL HARPENDEN
Harpenden Common.
W. BARNFIELD
SAWYERS
FOSTERS
LONG HOOS
LITTLE HOOS
HOOSFIELD
LONGCROFT
GT KNOTT
L.T KNOTT
BROADBALK
GT. HARPENDEN
N. ZEALAND
DELHARDING
Cunningham House
Cunningham Field
KNOTT WOOD
FURZE FIELD
BONES CLOSE
PASTURES
STACKYARD
PARKLANDS
GREAT FIELD
BARNFIELD
AGDELL
HARWOODS PIECE
CLAY CROFT
APPLE TREE
PARK GRASS
HIGH FIELD
Hatching Green.
To Redbourn.
DEACONS
ROAD PIECE
A.6 To St Albans.
Public Footpaths.
All other footpaths private.
1800 Feet
500
1/4
1 mile